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THE Psychological Review

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The Psychological Review

THE RETINA AND RIGHTHANDEDNESS[1]

BY H. C. STEVENS AND C. J. DUCASSE

I. (*a*) Introduction

The motives which have actuated experimental investigations into the capacity of the retina to estimate spatial extents have been various. The older observers, Fechner,[2] Volkman,[3] Chodin[4] and Fischer[5] were concerned mainly to prove or disprove the applicability of Weber's law to extensive magnitudes. Kundt[6] and Münsterberg[7] seem to have been interested chiefly in the light that constant errors in retinal space perception might throw upon the rôle of the eye muscles in judgments of extent. In a third class belongs the work of Highier[8] and Merkel[9] who carried out a series of experiments upon the estimation of retinal magnitudes for the purpose of furnishing numerical results for testing the validity of the psychophysical methods. The present work was also undertaken with a special end in view. In papers previously published[10] one of the authors has attempted to show that very essential differences, in space sense, exist between symmetrical positions upon non-corresponding halves of the two retinas. The purpose of the present paper is to demonstrate in a differ-

[1] From the Psychological Laboratory of the University of Washington.
[2] 'Elemente der Psychophysik,' II., 343.
[3] 'Physiologische Untersuchungen im Gebiete der Optik,' 1863.
[4] *Archiv f. Ophth.*, Bd. 23, S. 92.
[5] *Arch. f. Ophth.*, Bd. 37, S. 109.
[6] *Pogg. Annalen der Physik*, Bd. 120, S. 118.
[7] *Beiträge zur Exper. Psych.*, Heft 2, S. 125.
[8] *Phil. Studien*, Bd. 7, S. 232.
[9] *Phil. Stud.*, Bd. 9, SS. 53; 176; 400.
[10] Psych. Rev., 15, 69; 15, 373.

ent way and, perhaps, with greater rigor of method and technique the same fact anew.

For a statement of the results of the experiments we cannot do better than quote from a summary[1] already published. "Experiments[2] carried out during the past year, on the comparative sizes of objects which are seen in indirect vision, brought to light the fact that a marked difference in the perception of size exists between the right and left halves of the retinæ of the two eyes. The experiments were made with a perimeter.[3] The objects compared were the orbits described by two black spots which were borne upon the peripheries of two slowly moving white cardboard discs. The spots were attached to movable radii so that the orbit of the apparently larger disc could be reduced until it equaled, subjectively, the orbit of the smaller. In this way, quantitative measurements were made for four meridians, vertical, horizontal and two oblique (each inclined 45 degrees to the right and left of the vertical respectively) and for three parallels of latitude, 10°, 20° and 25° of the visual field. The observations were either (*a*) *peripheral comparisons* in which the discs were situated in the periphery of the field of vision upon some one of the four meridians upon opposite sides of (and at equal distances from) the fixation point; or (*b*) *foveal-peripheral* comparisons, in which one disc covered the fixation point and the other occupied some position in the periphery. The results of both (*a*) and (*b*) follow. (i) The discs upon the upper vertical, right-upper oblique, right horizontal and right-lower oblique meridians appear larger than similar discs symmetrically placed at opposite sides of the fixation point or at the fixation point. (ii) This result is constant for *both* eyes. (iii) The enlargement is greatest at 25° from the fixation point and least at 10°. (iv) The enlargement is greater in the right upper field than in the right lower field." Figures 1, 2, 3, and 4 of the article[2] already referred to show in graphic form each of the propositions just stated.

[1] *Science*, N. S., XXVII., 272.

[2] Psych. Review, XV., 69.

[3] For particulars concerning the apparatus, see the article in the Psych. Rev., XV., 69.

(*b*) Description of the Apparatus

The successful attack of a psychophysical problem requires an adequate form of apparatus. This truth was brought home to us only after making several hundred observations with a crude instrument which we were forced eventually to abandon. This instrument consisted of a meter stick, one side of which had been planed smooth and blackened, which was bolted through its middle point to a vertical standard about one meter in height. Attached to the standard was a protractor, from which the angular position of the meter stick which was capable of rotation about the bolt which attached it to the standard, could be determined. The head of the bolt served as the fixation point; the outer limits of the standard and variable extents were marked by two white threads held crosswise to the meter stick by two metal frames which could be slipped along the stick or fixed at chosen points. The observer sat with his head supported in a frame to secure uniformity of position, with one eye upon the fixation point while the experimenter moved to a point of subjective equality with the standard extent, the thread

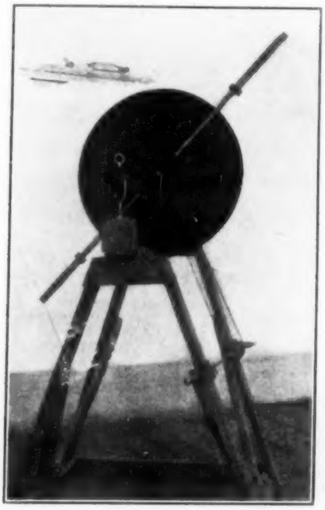


Plate I.

Plate II.

limiting the variable extent. Observations with three subjects with standard extents of 40 and 80 mm. yielded mean variations too large to be of use in reaching a solution of our problem. We were therefore compelled to design a more exact form of instrument.

Plates I. and II. give a general idea of the apparatus as a whole. A detailed description of the parts follows.

The diameter of the disc is 61 centimeters. It is made of galvanized iron, stiffened at the back as shown in the Plate II. by flat strips of metal 25 × 4 mm. riveted on. Black velvet is stretched on the front and held in place by sewing all round through holes drilled in the edge of the disc.

Figure 1, Plate III., shows a round plate *A*, 110 mm. in diameter, riveted to the center of the disc at the back. To this plate is screwed the sleeve *B* into which the hollow axis *C* (shown in dotted lines) fits and is secured by a set-screw, *K*. The large gear *E*, grooved wheel *F* (which receives the belt connecting with the cranks) and collar *G*, are in one piece, which revolves freely upon the axis *C*. *H* is a separate free collar between the face of the top plate *I* and the revolving piece *EFG*. *J* is a collar secured by set-screws to the end of the axis, to prevent it from sliding out of its tunnel in the top plate *I*. *K* is the thumb screw which secures the axis, and therefore the whole disc, in any desired position. *L* is a small blackened metal button on the face of the disc. It bears the center sight (fixation point) which is of silver and 2½ mm. in diameter. On each side of the sight, a small aperture is drilled through the button, opening into the drill hole which runs through the length of the axis *C*. This permits of using the apparatus not only for the comparison of empty intervals, but of filled magnitudes as well. To do this, two slender white cords are attached to the under surfaces of the flat sight-bearing pieces *M* by knotting the ends and slipping them into the slots shown in M_2, Fig. 4. The free ends of the cords are then passed through the apertures in the button, then through the hollow axis, and a lead weight attached to each to stretch them taut (Fig. 1*a*).

The remaining features of Fig. 1 require little explanation.

The arm P is of blackened metal 25×4 mm. and graduated in millimeters on the back as shown in Fig. 3. The collar N, Fig. 1, is attached to the rod S by a set screw and should be fitted closely enough against the face of the support Q, to prevent *any* lengthwise motion of the rod S, without, however, impeding its rotation. The thread on the rod S is exactly one millimeter, thus propelling the carriage R one millimeter to one turn. A small brass cylinder O bearing one hundred numbered divisions is secured to the rod S by a set-screw, and a pointer T is attached to the support Q_2. The passage under the pointer of one division of the cylinder therefore corre-

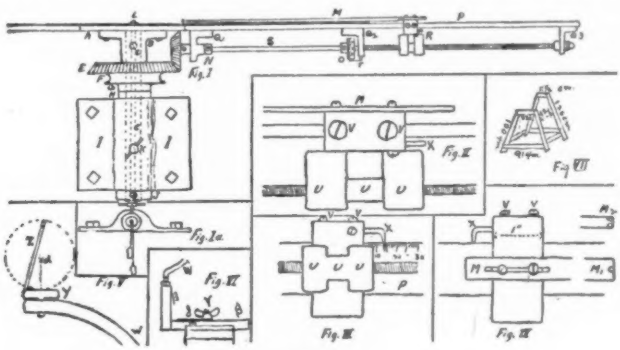


PLATE III.

sponds to a lateral displacement of the carriage (and connected sight) of one hundredth of a millimeter.

Different views of the carriage R are represented in Figs. 2, 3, and 4. The carriage itself is 25 mm. wide, but the threaded sleeve U into which the rod passes is 37 mm. long. This length was found necessary to prevent absolutely any looseness and to secure a positive displacement of the carriage to the slightest rotation of the rod S. The screws VV bear upon the upper edge of the arm P and permit of taking up any wobble of the carriage on the arm. X is the pointer for the millimeter scale. Fig. 4 shows the manner of attachment of the sight-bearing piece M to the face of the carriage. M represents the end of the sight-bearing piece with its silver sight 2½ mm. in diameter. M_2 is the obverse of M, and shows the end doubled under and slotted for receiving the

knotted end of the cord. The arm on the standard side of the disc is also graduated in millimeters. Its carriage and sight-bearer are similar to those on the variable side, except that no sleeve *U* is attached to the carriage, a thumb-screw being substituted to clamp it on the arm at any desired point.

Figures 5 and 6 represent the eye-piece and its support. The lower part of the curved rod *W* is threaded and fitted with a nut to permit of vertical adjustment. The wooden piece *BB* is slotted in the center and secured in any position desired by the winged nut *Y*. It is fitted with a scale and pointer *S* indicating the distance between the point α (Fig. 5) and the center sight fixation point on the disc. The upper end of the curved rod *W* is flattened and drilled, the table-shaped piece *Y* revolving freely, but without wobble, in the drill hole. To the piece *Y* is soldered the ring *Z* at such an angle that when the eye is applied to it and the line of sight directed to the center sight on the disc, that part of the anterior surface of the cornea which is in the line of sight, occupies the point α. This point, which measures 525 mm. from the fixation point, is at the intersection of the vertical axis of the piece *Y* and of a line passing through the center of the center sight on the disc, and perpendicular to it.

The construction of the stand is shown in Plates I. and II. and Fig. 7. It is made of hardwood 15×75 mm. The dimensions are indicated in Fig. 7. The machine can be operated either by the person who observes or by the person who records. A black velvet curtain with a circular opening 59 cm. in diameter should be hung directly in front of the disc. Subdued artificial light was used to insure equal illumination throughout the experiments.

(*c*) Conditions of Experimentation

The apparatus permits of observation under a great variety of conditions.

i. With a solid white line for either the standard or variable extent or both.

ii. With a black extent limited by two white spots for either standard or variable or both.

iii. With comparisons in any meridian of the field of vision.

iv. With adjustment made either by the experimenter or by the observer.

vi. With standard or variable extent upon the same or opposite side of the fixation point.

vii. With standard and variable extents separated by an interval or adjacent to one another.

In our own experiments the standard and variable were black extents limited by white spots; adjustments were made by the observer; standard and variable lay upon opposite sides of the fixation point; and the extents were adjacent to each other at the fixation point. All of the observations were made with one eye at a time. The eye with which the observation was made was always fixed upon the fixation point; during an observation it never moved. The non-observing eye was covered by a screen or held shut. Between observations the observing eye was turned towards the floor. Observations were always made with a regular alternation of right and left eyes after ten readings. Standard and variable extents were presented alternately on opposite sides of the fixation point.

After repeated attempts in different rooms of the laboratory, to find a uniform and equally distributed source of light, we were forced to have recourse to the dark room, where errors due to unequal illumination and reflections from walls and ceiling could be eliminated. With an illumination of about four candle power, the limiting white spots stood out against the black velvet background with clearness. To cut off reflected light which brought out the difference in blackness between the black of the velvet and that of the painted sight carriers, black curtains were suspended in front of the apparatus.

The method used in these experiments was that form of the method of average error which Müller[1] calls 'the determination of equivalent stimuli by means of the method of limits.' The constant error for the reproduction of each standard extent in each of the four meridians investigated

[1] 'Die Gesichtspunkte und die Thatsachen der psychophysischen Methodik,' p. 201.

was determined from forty settings of the variable extent. Of these settings, twenty were from greater to equal and twenty from less to equal. The readings were made by one of the authors from a position behind the apparatus and written upon a card printed for the purpose. The card, a specimen of which is here shown, records the meridian, the side upon which the standard lies, the eye used, the individual readings (Fehlreizen in Müller's terminology) in the order in which they were taken, the average of the readings, the constant error, the mean variation of the readings, and the probable error for the series.[1]

Standard: 40 mm.	Angle: 135°.	Eye: Left.
Mean: 44.61.	C.e. = 4.61.	M.v. = 1.53. $Pe_m = 0.208$.

O. Dr. Magnusson.
E. C. J. D.
Date, Nov. 18, 1908.
Time 11:30 A.M.

1.	G. to E.	45.93
2.	L. to E.	43.89
3.	G. to E.	44.57
4.	L. to E.	44.00
5.	G. to E.	48.23
6.	L. to E.	45.64
7.	G. to E.	46.62
8.	L. to E.	44.24
9.	G. to E.	44.61
10.	L. to E.	43.65
11.	G. to E.	49.69
12.	L. to E.	46.13
13.	G. to E.	48.21
14.	L. to E.	47.63
15.	G. to E.	47.00
16.	L. to E.	44.01
17.	G. to E.	44.04
18.	L. to E.	42.72
19.	G. to E.	46.70
20.	L. to E.	46.58
21.	G. to E.	45.57
22.	L. to E.	42.49
23.	G. to E.	44.10
24.	L. to E.	41.10

[1] The probable error of the series was computed from the approximate formula given by Titchener, 'Experimental Psychology,' Vol. II., Pt. 1, p. 65.

$$P_{em} = \frac{0.85\, MV}{\sqrt{n-1}}$$

25.	G. to E.	45.55
26.	L. to E.	43.18
27.	G. to E.	42.95
28.	L. to E.	42.80
29.	G. to E	44.30
30.	L. to E.	42.10
31.	G. to E.	44.10
32.	L. to E.	43.20
33.	G. to E.	44.30
34.	L. to E.	42.20
35.	G. to E.	42.30
36.	L. to E.	42.25
37.	G. to E.	44.25
38.	L. to E.	45.80
39.	G. to E.	44.77
40.	L. to E.	43.35
		1784.75

The arithmetical mean of the twenty greater to equal (G. to E.) readings gives the F_0 of Müller, or that extent which no longer appears greater than the standard which in this case is 45.38; the arithmetical mean of the twenty less to equal (L. to E.) readings gives the F_u of Müller, or that extent which no longer appears smaller than the standard, in this case 43.84. The difference of F_0 from the standard gives the average G. to E. error, Δ_0 or 5.38; similarly, the difference of F_u from the standard gives the average L. to E. error, Δ_u or 3.84; then $\frac{\Delta_0 + \Delta_u}{2} = 4.61$, the constant error.

The constant error for eight positions in the field of vision was thus determined for each standard from forty readings for each position making in all 320 observations for each eye, or 640 for each standard. With the three standards 40, 80 and 200 mm. 1,920 observations were made by each of the four observers, Mr. H. L. Osterud, graduate assistant in the department of zoölogy, Dr. C. E. Magnusson, professor of electrical engineering, and the two authors, C. J. D. and H. C. S.

The angles subtended by the three standards, determined at a distance of 525 mm., the distance of the fixation point from the surface of the cornea, plus 7 mm. as the distance from the surface of the cornea to the nodal point of the lens was 4° 5′ for 40 mm., 8° 33″ for 80 mm. and 20° 36″ for 200 mm.

(*d*) Review of the Literature

It is not the intention of the authors to review the extensive literature of 'Augenmass.' There have been reported, however, by certain authors differences in results of the right and left lying extents which might indicate that the position in the field of vision of the standard or variable, influences the judgment of extent. It is with such authors that we are now concerned. August Kundt[1] in his 'Untersuchungen über Augenmass und optische Täuschungen' was the first to obtain results which point to an influence of position on the judgment of extent. His paper is divided into two parts: I. Das Schätzen der Distanzen and II. Das Schätzen der Winkel und die optischen Täuschungen. It is only with the first part that we are now concerned. The apparatus consisted of a wooden screen in which two eyeholes and a place for the nose were cut, supported upon vertical rods at the end of a table. Upon the table in such a position that the eyes of the observer looked down upon it, was a wooden block in which projecting pegs could be set and beneath which the points of a pair of compasses could be placed in such a manner that the points of the compass formed one of the limiting points of the extent and the variable middle point which was set by hand. The remaining pegs allowed comparisons to be made between filled and empty intervals. The error made in setting the movable compass point in the middle of the total extent, was determined. The eyes were used separately. The length of the total extent was 241.9 mm. The distance from the nodal point of the lens to the middle of the extent was 338 mm. The distance between the pegs was varied in different experiments. As is well known, Kundt found that the filled extent was overestimated. After establishing this result in three series of experiments, Kundt made a fourth series of observations with empty intervals. The problem was to determine the middle point of an extent 100 mm. long. The distance from the nodal point was 226 mm. and the number of observations 79. The results show a difference between the right and left eyes.

[1] *Annalen der Physik und Chemie*, Bd. CXX., S. 118, 1863.

	Left Eye	Right Eye
Mean	50.33	49.845
MV	0.50	0.66
Pe	0.05	0.07

The distances just given were measured from the right end of the extent to the apparent middle. Thus for the right eye the right lying extent was overestimated and with the left eye, the left lying extent. In both cases the extent whose retinal image fell upon the nasal retina was overestimated.

"Es bleibt nun noch der Fehler bei den Halbirungsversuchen ohne eingeschobene Spitzen zu erklären. Sind zwei einfache Distanzen gegeben, die in einer zur Sehaxe senkrechten Geraden neben einander liegen und ist der gemeinshaftliche Punkt derselben fixirt, so werden, wenn die Distanzen gleich sind, auch ihren scheinbaren Grössen genau dieselben sein, wenn wirklich das Auge eine Kugel wäre. Nun ist bekannt dass das Auge in den verschiedenen Richtungen verschiedene Krümmungen hat, es lässt sich aber auch annehmen, dass in einem einzigen, z. B., dem horizontal Schnitt, die Krümmung nicht an allen Stellen dieselbe ist. . . . Es müssen daher auch die scheinbaren Grössen der Distanzen an den verschiedenen Stellen verschieden sein. Unsere Versuche ergeben, dass die scheinbare Grösse einer Distanz auf der einen Seite eine andere ist, als auf der andern, und zwar liegen die Stellen der gleichen Schätzung in beiden Augen symmetrisch, man schätz in beiden Augen eine Distanz, die nach Aussen liegt zu klein. Die dadurch angezeigte Symmetrie in der Krümmung des horizontalen Schnittes der Netzhaut dürfte vielleicht durch den Eintritt des Sehnerven bedingt sein" (p. 138).

One wonders why a physicist should have been at pains to explain a constant error which was considerably less than the mean variation of the observations.

R. Fischer[1] made comparisons between straight lines situated in different parts of the field of vision. His problem was to determine the capacity of the retina to estimate the length of lines. His apparatus consisted of two flat, blackened

[1] 'Grössenschätzungen im Gesichtsfeld,' *Arch. f. Ophth.*, XXXVII., Abth. I., pp. 97–136.

strips fastened together at their middle points, so as to form a rectangular cross. The standard and variable extents were marked by iron bands. Measurements were made to 1/10 mm. The standard extent was presented in the following order: to the left, below, to the right, above and the variable to the right, above, to the left and below. Readings from greater to equal alternated with those from less to equal. The fixation point was 200 mm. from the eyes. In the results which are quoted here both eyes were used. The observations were made under two somewhat different conditions. In one case the middle point between two termini was determined; in the other case, one extent was made equal to the other. In his experiments with horizontal extents several standards were used: 11.2; 15.9; 23.8; 34.2; 48.2; 68.4; 96.0 mm. Here the middle point between two extremes was determined. A constant error of 0.79 mm. resulted as the mean of all his observations with these standards. Expressed as a proportion, the right extent is to the left extent as 100 is to 100.79. In another series of horizontal comparisons with the following standards 6.7; 11.4; 17.2; 24.8; and 42.2 mm., the result was similar to that just stated. The constant error amounted to 3.24 mm. Expressed as a proportion, the right extent is to the left extent as 100 is to 103.24. Both experiments show that the left extent was underestimated and the right extent overestimated, a result which agrees with our own observations.

Two other observers have reported differences. Highier[1] determined by means of the method of average error the accuracy with which a variable extent could be made equal to a standard extent. The standard extents were 10, 20, 50, 100, 150, 200 and 250 mm. in length. The right eye alone was used and the distance from the apparatus was 500 mm. The apparatus consisted of a glass plate covered with black paper in which a slit ½ mm. in width and 750 mm. in length was cut. The standard and variable extents were marked by vertical wires. The apparatus was so arranged that light came through the slit from behind. The dependence of the

[1] *Phil. Studien*, VII., 232.

constant error upon the position of the extents in the field of vision may be stated in the author's own words.[1]

"Was die Eigenthümlichkeiten des constanten Fehlers in Bezug auf die Raumlage betrifft (s. Tab. V.), so wiederholt sich auch hier das beim variablen Fehler Beobachtete: C_l $(a_r' - a)$ ist ausnahmslos bedeutend grösser als das entsprechende C_r. Ich überschätze mithin die linksliegende Normaldistanz immer mehr als die rechtsliegende—ganz abgesehen davon, ob sie verhältnissmässig gross oder klein ist. Eine analoge constante Ueberschätzung, bei monocularem Sehen, der dem benutzten Auge heteronomen Seite ist Aubert und Kundt aufgefallen, wenn auch dieselben im allgemeinen mit kleineren Distanzen als ich operirten" (p. 244).

Muensterberg[2] made some 20,000 observations with an apparatus the principle of which he describes as follows. "Versuchen . . . wurden an einem einfachen Apparat ausgeführt, dessen Princip folgendes war. Auf einer dunklen, zur primär gestellten Blicklinie senkrechten Fläche sollten unter jeder möglichen Variation der Bedingungen helle Punkte und Linien sich in jeder Lage einstellen und verschieben lassen und dennoch im Blickfeld völlig isoliert bleiben, so dass die bewegenden Hände und Hilfsmittel nicht gesehen würden. Unter Punkten, die ich absichtlich nicht zu klein wählte, damit sie auch bei indirektem Sehen deutlich blieben, verstehe ich im folgenden durchweg Flächen von genau 1 qmm mit einem für die Messung benutzten Nadelstichpünktchen in ihrer Mitte; unter Linien verstehe ich durchweg Flächen, deren Breite 1 mm beträgt" (p. 150). Standard distances were 10, 20, 30, 40, 50 up to 200 mm. In the horizontal meridian, he found that the left extent was overestimated and the right extend underestimated. Of this difference he says:

"Am auffallendsten scheint mir für meine gesamten Resultate eine konstante Ueberschätzung der linken und Unterschätzung der rechten Grösse. Während sie bei normalen Sehen mit bewegtem Doppelauge sich als + 2.2 pro zent. fur die Einstellung der rechten, − 1.6 pro zent. fur die

[1] *Loc. cit.*, 224.

[2] *Beiträge zur Experimentellen Psychologie*, Heft 2, 125.

der linken ergibt, sehen wir unter künstlichen Bedingungen, wie der Benutzung eines fixierten Auges, den Fehler rechts bis über + 20 pro zent. steigen, und zwar ist fast immer der positive Fehler rechts grösser als der negative links, so dass zu dem Raumlagefehler, der dort positiv, hier negativ wirkt, jedenfalls noch ein zweiter Fehler kommt, der *V* im Verhaltnis zu *N* stets in derselben Richtung beeinflusst. In einzelnen Fällen, wo offenbar andere Bedingungen eine Ueberschätzung der Normal distanz mit sich brachten, konnten die Fehler sowohl rechts wie links positiv werden, der Unterschied zwischen beiden blieb aber auch dann unverhältnismässig hoch und hatte dieselbe Richtung. Eine Erklärung für den einfachsten Fall, das normale Sehen, liegt nahe. Wir sind durch unsere dauernde Lese- und Schreibegewohnheit alle eingeübt, die Augen leicht von links nach rechts zu bewegen, führen sie aber nur mit einer kleinen Anstrengung in gerader Linie von rechts nach links, da wir gewohnt sind, sie beim Lesen in Bogenlinien vom Ende der einen zum Anfang der nächsten Zeile zurücksubewegen, Erfahrungen, die schon Purkinje und Joh. Muller erwähnen"[1] (p. 167).

II. Results of Our Own Experiments

The outcome of our experiments is shown in Tables I., II., III. and IV. and, graphically, in Figs. 8, 9, 10 and 11. In both tables and figures the results for each observer and for each standard are kept separate. In the tables three quantities are determined: the constant error, *CE*; the mean variation *MV*, of a series of 40 observations; and the probable error of the series, *PEm*, calculated from the *MV* by the approximate formula already referred to. Furthermore, the results for the right and left eyes are separately stated in the tables. The positions of the standard and variable extents are described in degrees of the field of vision.

180° is the horizontal meridian with the variable on the right.

[1] James' comment ('Principles of Psychology,' II., 201) on this explanation is worth noting in this connection. "Now I have been a reader for more years than Herr Munsterberg; and yet with me there is a strongly pronounced error the other way. It is the rightward-lying interval which seems to me longer than it really is."

TABLE I

Position	Standard 40 mm.						Standard 80 mm.						Standard 200 mm.					
	R. Eye			L. Eye			R .Eye			L. Eye			R. Eye			L. Eye		
	CE	*MV*	*PEm*	*CE*	*MV*	*PEm*	*CE*	*MV*	*PEm*	*CE*	*MV*	*PEm*	*CE*	*MV*	*PEm*	*CE*	*MV*	*PEm*
180°	+1.24	1.55	.211	+1.81	1.27	.172	−3.52	3.88	.528	−3.60	1.80	.245	−10.56	3.90	.517	− 5.67	4.37	.581
0°	+0.34	1.30	.177	+0.26	1.54	.210	+4.41	2.10	.286	+2.92	1.56	.212	+11.01	6.16	.823	+ 2.62	3.95	.524
315°	+0.19	1.17	.159	+0.21	0.91	.123	+2.13	1.86	.253	+0.46	2.08	.283	− 6.94	5.60	.699	− 4.01	5.73	.716
135°	+0.66	1.09	.148	+0.36	0.97	.132	+1.05	2.30	.313	+0.75	2.46	.335	− 1.64	8.36	1.111	− 3.38	4.27	.568
90°	+3.70	1.50	.204	+4.05	1.00	.135	+8.25	1.80	.245	+6.85	1.69	.230	− 6.95	2.72	.369	− 4.50	3.55	.482
270°	−3.10	0.90	.122	−2.80	0.90	.122	−5.07	1.28	.174	−5.29	1.14	.155	−30.93	2.30	.311	−31.53	2.69	.365
45°	+2.71	0.99	.134	+2.30	0.91	.123	+2.80	2.62	.357	+2.37	1.94	.264	+15.23	6.62	.887	+ 6.26	4.67	.572
225°	−0.30	0.92	.124	−0.78	0.72	.098	−3.38	1.19	.162	−3.53	1.29	.176	−15.00	3.97	.527	−10.57	4.21	.559

TABLE II

Position	Standard 40 mm.						Standard 80 mm.						Standard 200 mm.					
	R. Eye			L. Eye			R .Eye			L. Eye			R. Eye			L. Eye		
	CE	*MV*	*PEm*	*CE*	*MV*	*PEm*	*CE*	*MV*	*PEm*	*CE*	*MV*	*PEm*	*CE*	*MV*	*PEm*	*CE*	*MV*	*PEm*
180°	+1.73	1.51	.205	+1.85	1.15	.156	+ 6.88	3.18	.432	− 0.73	2.16	.292	−11.25	1.16	.157	−11.79	7.35	.986
0°	+2.20	1.04	.141	+2.47	1.15	.156	+ 1.78	2.14	.289	+ 4.94	1.53	.208	+10.89	4.98	.614	+ 5.08	6.59	.883
315°	−0.93	1.43	.194	−0.15	1.18	.160	− 8.21	2.59	.351	− 1.96	1.94	.263	− 4.18	10.24	1.317	− 0.09	7.27	.975
135°	+4.96	2.15	.292	+4.74	1.41	.192	+16.18	2.50	.339	+10.32	3.20	.434	− 3.43	5.79	.724	+ 6.39	8.80	1.121
90°	+2.75	1.38	.188	+3.09	1.24	.168	+ 5.31	2.22	.300	+ 3.10	2.42	.328	− 3.21	5.91	.741	− 7.30	6.45	864
270°	−0.29	1.33	.181	−0.48	1.13	.154	+ 0.70	2.81	.381	+ 1.85	2.62	.355	+ 0.93	9.35	1.296	− 3.91	4.15	.551
45°	+2.87	1.88	.252	+2.00	1.31	.178	+ 0.49	2.35	.318	+ 7.72	3.61	.490	+ 4.08	10.55	1.309	− 5.33	9.88	1.268
225°	+0.92	1.74	.232	−0.26	0.99	.134	− 4.66	2.65	.360	− 4.55	1.95	.265	− 1.08	13.33	1.814	− 6.93	17.41	2.371
													− 5.77	7.91	1.050	− 7.80	5.76	.720

TABLE III

Position	Standard 40 mm. R. Eye CE	Standard 40 mm. R. Eye MV	Standard 40 mm. R. Eye PEm	Standard 40 mm. L. Eye CE	Standard 40 mm. L. Eye MV	Standard 40 mm. L. Eye PEm	Standard 80 mm. R. Eye CE	Standard 80 mm. R. Eye MV	Standard 80 mm. R. Eye PEm	Standard 80 mm. L. Eye CE	Standard 80 mm. L. Eye MV	Standard 80 mm. L. Eye PEm	Standard 200 mm. R. Eye CE	Standard 200 mm. R. Eye MV	Standard 200 mm. R. Eye PEm	Standard 200 mm. L. Eye CE	Standard 200 mm. L. Eye MV	Standard 200 mm. L. Eye PEm
180°	+0.19	0.46	.062	−0.41	1.30	.177	−0.69	4.14	.550	+0.07	2.35	.318	− 0.37	7.43	.997	− 3.69	7.74	.985
0°	+0.78	1.10	.149	+1.79	1.34	.182	+2.38	2.73	.370	+1.43	1.77	.240	− 4.51	8.71	1.109	−11.52	5.20	.644
315°	−0.91	1.55	.211	+0.21	1.09	.148	+1.16	2.08	.283	+3.72	2.41	.327	+11.03	8.65	1.102	+ 5.44	8.40	1.117
135°	+2.78	1.25	.169	+2.02	1.07	.145	−1.71	2.23	.301	−3.42	2.20	.297	−17.40	9.97	1.280	−20.89	8.53	1.194
90°	+2.48	1.40	.191	+1.68	0.87	.118	−3.82	1.73	.235	−3.08	2.93	.398	− 7.92	8.23	1.094	−24.27	7.45	1.000
270°	−0.92	1.23	.167	+0.01	0.95	.129	+1.14	2.11	.285	+0.37	3.52	.478	+ 0.10	7.28	.977	+ 0.41	5.57	.694
45°	+1.06	1.10	.149	+1.82	0.81	.110	+2.87	2.76	.376	−1.47	1.74	.232	−21.27	8.84	1.127	−27.71	6.43	.861
225°	−0.42	1.12	.153	+0.11	1.13	.154	−0.03	1.87	.254	+0.56	2.55	.347	− 3.56	8.45	1.124	− 6.56	9.02	1.151

TABLE IV

Position	Standard 40 mm. R. Eye CE	Standard 40 mm. R. Eye MV	Standard 40 mm. R. Eye PEm	Standard 40 mm. L. Eye CE	Standard 40 mm. L. Eye MV	Standard 40 mm. L. Eye PEm	Standard 80 mm. R. Eye CE	Standard 80 mm. R. Eye MV	Standard 80 mm. R. Eye PEm	Standard 80 mm. L. Eye CE	Standard 80 mm. L. Eye MV	Standard 80 mm. L. Eye PEm	Standard 200 mm. R. Eye CE	Standard 200 mm. R. Eye MV	Standard 200 mm. R. Eye PEm	Standard 200 mm. L. Eye CE	Standard 200 mm. L. Eye MV	Standard 200 mm. L. Eye PEm
180°	−2.86	1.00	.135	−2.59	0.94	.128	−4.39	2.64	.358	−4.52	2.22	.300	−19.77	8.38	1.114	−26.82	7.31	1.104
													−24.86	6.47	.866	−23.75	5.42	.674
0°	+3.15	1.06	.144	+3.35	0.92	.124	+4.22	2.24	.303	+5.71	3.27	.444	+ 4.92	8.30	1.100	− 0.82	9.25	1.180
													+ 2.32	7.40	.993	− 0.52	5.03	.621
315°	+2.20	1.05	.142	+1.27	1.20	.163	+6.26	3.75	.509	+2.25	2.27	.306	+24.52	7.26	.974	+13.81	7.40	.993
135°	+0.37	1.33	.181	+0.22	1.56	.212	−2.84	4.52	.614	−3.20	2.54	.345	−30.49	5.46	.679	−23.55	7.20	.996
90°	+0.35	0.91	.123	−0.15	1.29	.176	−1.46	2.81	.381	−4.15	2.52	.342	−19.35	4.35	.579	−24.61	5.56	.693
270°	−1.02	1.33	.181	+0.62	1.39	.189	−0.33	1.79	.243	+2.40	2.20	.297	+12.59	5.31	.659	+14.31	4.15	.551
45°	+3.67	1.14	.155	+3.53	1.40	.191	+4.68	2.26	.306	+3.46	2.51	.341	−11.60	5.68	.709	−15.47	6.59	.833
225°	−1.47	1.92	.259	−1.66	1.18	1.60	−1.22	2.43	.330	−1.06	2.43	.330	−16.49	6.10	.767	−14.87	6.45	.864

0° is the horizontal meridian with the variable on the left.

315° is the right oblique meridian[1] with the variable on the right.

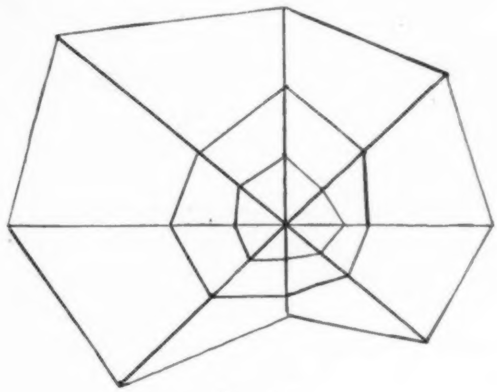


FIG. 8.

135° is the right oblique meridian with the variable on the left.

90° is the vertical meridian with the variable above the fixation point.

270° is the vertical meridian with the variable below the fixation point.

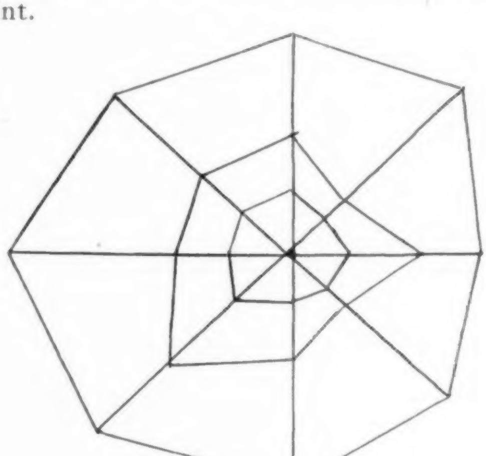


FIG. 9.

[1] The right oblique meridian slopes from the right, upper quadrant of the field of vision, to the left, lower quadrant, inclined 45° from the vertical. The left oblique meridian slopes from the left, upper quadrant of the field of vision, to the right, lower quadrant, inclined 45° from the vertical.

45° is the left oblique meridian with the variable to the left.

225° is the left oblique meridian with the variable to the right.

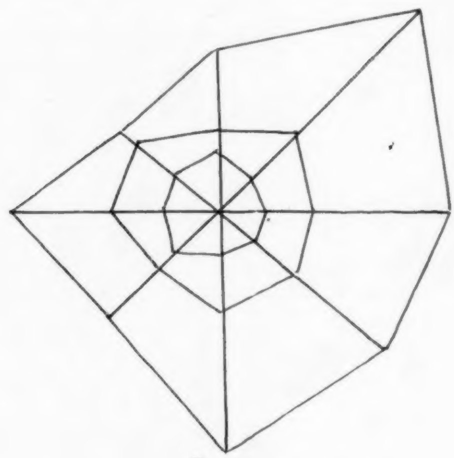


Fig. 10.

Figs. 8, 9, 10 and 11 show the positions of the meridians in the field of vision. The results of observers H. L. O.,

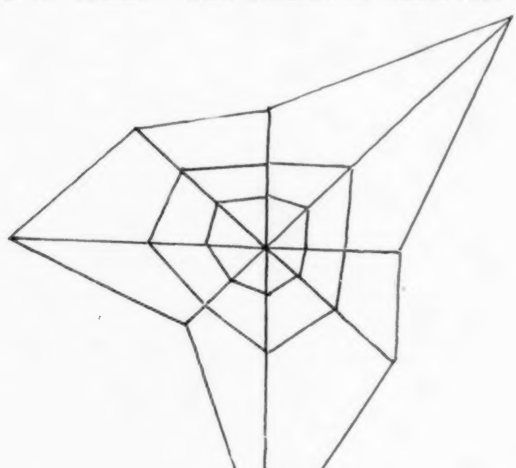


Fig. 11.

C. E. M., C. J. D. and H. C. S. are given in Tables I., II., III. and IV., respectively.

The constant error is the significant quantity in our tables. By its variation in the field of vision, the variation of the over- and underestimation of the variable becomes apparent. These variations are shown graphically in Figs. 8, 9, 10 and 11. The figures were plotted from Tables I., II., III. and IV. by reducing one fourth each of the standard distances. The 40 mm. standard thus becomes 10 mm.; the 80 mm. standard 20 mm.; and the 200 mm. standard 50 mm. To each of these reduced standards the constant error (the average of the two eyes was taken) is added or subtracted according to its sign. The ratio of the *CE* to the standard is thus magnified fourfold and the direction and amount of the variation made visibly very conspicuous.

For the purposes of analysis the results for each observer, for each standard, in each meridian, are stated in words, in terms of over- and underestimation of the variable. For the sake of brevity this statement takes the form of a catalogue.

With H. L. O., for the 40 mm. standard,
- in the horizontal meridian, the right extent is underestimated;[1]
- in the right oblique meridian, the right extent is slightly overestimated relative to the left extent, but is absolutely underestimated;
- in the vertical meridian, the upper extent is underestimated and the lower overestimated;
- in the left oblique meridian, the right extent is overestimated.

For the 80 mm. standard,
- in the horizontal meridian the right extent is overestimated; the left, symmetrical extent is underestimated;
- in the right oblique meridian, the right extent is underestimated; the left symmetrical extent is underestimated but less so than the right extent;
- in the vertical meridian, the upper extent is underestimated and the lower extent overestimated;
- in the left oblique meridian, the left extent is underestimated and the right extent overestimated.

For the 200 mm. standard,
- in the horizontal meridian, the right extent is overestimated; the left extent is underestimated;
- in the right oblique meridian, the right extent is overestimated; the left extent is underestimated:

[1] Underestimation of a variable extent means that, with respect to the standard extent, an excess of objective space had to be added to the variable in order to produce the same feeling of spatial magnitude as that produced by the standard extent. Overestimation means that a lesser spatial magnitude was able to produce the same feeling of extent as that produced by the standard spatial magnitude.

in the vertical meridian, the upper extent is overestimated; the lower extent is also overestimated and more than the upper extent;

in the left oblique meridian, the left extent is underestimated; the right extent is overestimated.

With C. E. M., for the 40 mm. standard,

in the horizontal meridian, the right extent is underestimated; the left extent is underestimated more than the right extent;

in the right oblique meridian, the right extent is overestimated; the left extent is underestimated.

in the vertical meridian, the upper extent is underestimated; the lower extent is overestimated;

in the left oblique meridian, the left extent is underestimated; the right extent is overestimated by the left eye and underestimated by the right eye.

For the 80 mm. standard,

in the horizontal meridian, the right extent is underestimated considerably by the right eye and the left extent slightly by the left eye;

in the right oblique meridian, the right extent is overestimated; the left extent is underestimated;

in the vertical meridian, both upper and lower extents are underestimated, the upper more than the lower;

in the left oblique meridian, the left extent is underestimated; the right extent is overestimated.

For the 200 mm. standard,

in the horizontal meridian, the right extent is overestimated; the left extent is underestimated;

in the right oblique meridian, the right extent is overestimated; the left extent is underestimated;

in the vertical meridian, the upper extent is overestimated; the lower extent is slightly underestimated by the right eye and decidedly overestimated by the left eye;

in the left oblique meridian, the left extent is underestimated by the right eye and overestimated by the left eye; the right extent is overestimated.

With C. J. D., for the 40 mm. standard,

in the horizontal meridian the right extent is slightly underestimated by the right eye and is overestimated by the left eye; the left extent is underestimated;

in the right oblique meridian, the right extent is overestimated by the right eye and underestimated by the left eye; the left extent is underestimated;

in the vertical meridian, the upper extent is underestimated; the lower extent is overestimated by the right eye and underestimated by the left eye;

in the left oblique meridian, the left extent is underestimated; the right extent is overestimated by the right eye and slightly underestimated by the left eye.

For the 80 mm. standard,

in the horizontal meridian, the right extent is overestimated; the left extent is underestimated;

in the right oblique meridian, the right extent is underestimated; the left extent is overestimated;

in the vertical meridian, the upper extent is overestimated; the lower extent is underestimated;

in the left oblique meridian, the left extent is underestimated by the right eye and overestimated by the left eye; the right extent is slightly underestimated by the left eye.

For the 200 mm. standard,

in the horizontal meridian, the right extent is overestimated; the left extent is overestimated more than the right extent;

in the right oblique meridian, the right extent is underestimated; the left extent is overestimated;

in the vertical meridian, the upper extent is overestimated; the lower extent is underestimated;

in the left oblique meridian, the left extent is overestimated; the right extent is also overestimated but much less than the left.

With H. C. S., for the 40 mm. standard,

in the horizontal meridian, the right extent is overestimated; the left extent is underestimated;

in the right oblique meridian, the right extent is underestimated; the left extent is underestimated, but less so than the right;

in the vertical meridian, the upper extent is underestimated by the right eye; the lower extent is overestimated by the right eye and underestimated by the left eye;

in the left oblique meridian, the left extent is underestimated; the right extent is overestimated.

For the 80 mm. standard,

in the horizontal meridian, the right extent is overestimated; the left extent is underestimated;

in the right oblique meridian, the right extent is underestimated; the left extent is overestimated;

in the vertical meridian, the upper extent is overestimated; the lower extent is overestimated by the right eye and underestimated by the left eye;

in the left oblique meridian, the left extent is underestimated; the right extent is overestimated.

For the 200 mm. standard,

in the horizontal meridian, the right extent is overestimated; the left underestimated;

in the right oblique meridian, the right extent is underestimated; the left extent is overestimated;

in the vertical meridian, the upper extent is overestimated; the lower extent is underestimated;

in the left oblique meridian, the left extent is overestimated; the right extent is overestimated, somewhat more than the left.

The significance of the results is not immediately apparent from this catalogue of over- and underestimation. If, however, the results are grouped according to the over- and underestimation of the variable extent with respect to each meridian and to each standard, the almost consistent overestimation of the right half of the *horizontal* and right *oblique* meridians, becomes apparent. The R. plus or L. plus in Table V. means that the right or left extent was overestimated in the sense explained in the footnote on page 19. Ur. plus

and Lr. plus means that the upper and lower extent was overestimated.

TABLE V

Meridian	H. L. O.		C. E. M.		C. J. D.		H. C. S.	
	R. +	L. +	R. +	L. +	R. +	L. +	R. +	L. +
Right oblique....	3	0	3	0	2	1	3	0
Horizontal.......	3	0	2	1	2	1	3	0
Left oblique.....	2	1	3	0	1	2	0	3
	Ur. +	Lr. +	Ur. +	Lr. +	Ur. +	Lr. +	Ur. +	Lr. +
Vertical.........	0	3	1	2	2	1	2	1

The figures in the table signify that the right or left variable was overestimated for a certain number of the standard extents. Thus H. L. O. overestimated the right extent in the horizontal meridian for each of the three standards. Again C. J. D. overestimated the right extent in the right oblique meridian for two standards and overestimated the left extent in the same meridian for one standard.

The results for the left oblique meridian show considerable divergence. Two observers, H. L. O. and C. E. M., consistently overestimate the right extent; on the other hand C. J. D. and H. C. S. as consistently overestimate the left extent. Similarly in the vertical meridian, two observers, H. L. O. and C. E. M., overestimate the lower extent while C. J. D. and H. C. S. overestimate the upper extent. Why there should be this divergence of result for the left oblique meridian, the authors are unable to explain. On the other hand, the mixed outcome of the comparisons in the vertical meridian was perhaps to have been expected, inasmuch as previous experimentation upon the same problem has not resulted in a unamimous verdict.[1]

III. Discussion of the Results

It remains to consider the significance of the overestimation of the right halves of the horizontal and right oblique meridians where the results of our observations are practically unanimously in accord. It should be noticed (1) that both eyes are substantially in agreement not only with regard

[1] Cf. R. Fischer, *loc. cit.*

to the direction of the overestimation but also with regard to the amount. It follows from this fact that corresponding halves of the retinas have an identical space sense not only with respect to the kind of constant space error but also with respect to its magnitude. (2) Objects situated in the right half of the periphery of the field of vision will appear larger than similar objects situated in the left half of the field of vision, for the reason that the retinal images of the objects in the right half of the field of vision will be formed upon the left corresponding halves of the retina and therefore will suffer a considerable overestimation. (3) The cause of the phenomenon lies in some as yet unknown anatomical or physiological condition peculiar to the left corresponding halves of the retina in virtue of their connection with the left hemisphere of the brain. This suggestion derives weight from the mode of origin of the optic nerves. Unlike the sensory portions of the cranial and spinal nerves which arise from groups of cells which have migrated from the neural crest the so-called optic nerves arise as tubular outgrowths from the diencephalon. The distal portion of the optic vesicle by the intussusception of the bulb forms the retina; the slender elongated portion of the vesicle, the optic stalk, forms the optic nerve. There is therefore some justification for Gould's somewhat anthropomorphic notion[1] that 'the brain itself comes out to see.' The peculiar position of the optic nerve is clearly shown in the excerpt which follows from 'The Development of the Human Body,' J. Playfair McMurrich, p. 492. "From what has been stated above it will be seen that the sensory cells of the eye belong to a somewhat different category from those of the other sense organs. Embryologically they are a specialized portion of the mantle layer of the medullary canal. Whereas in the other organs they are peripheral structures either representing or being associated with representatives of the posterior root ganglion cells. Viewed from this standpoint, and taking into consideration the fact that the sensory portion of the retina is formed from

[1] 'Righthandedness and Lefthandedness,' p. 18.

the invaginated part of the optic bulb, some light is thrown upon the inverted arrangement of the retinal elements, the rods and cones being directed away from the source of light. The normal relations of the mantle layer and the marginal velum are retained in the retina and the latter serving as a conducting layer for the axis cylinders of the mantle layer (ganglion) cells, the layer of nerve fibers becomes interposed between the source of light and the sensory cells. Furthermore, it may be pointed out that if the differentiation of the retina be imagined to take place before the closure of the medullary canal—a condition which is indicated in some of the lower vertebrates—there would be then no inversion of the elements, this peculiarity being due to the conversion of the medullary plate into a tube, and more especially to the fact that the retina develops from the outer wall of the optic cup. In certain reptiles in which the eye is developed in connection with the epiphysial outgrowths of the diencephalon, the retinal portion of this pineal eye is formed from the inner layer of the bulb, and in this case there is inversion of the elements.

"A justification of the exclusion of the optic nerve from the category which includes the other cranial nerves has now been presented. For if the retina be regarded as a portion of the central nervous system, it is clear that the nerve is not a nerve at all in the strict sense of that word, but is a tract confined throughout its entire extent within the central nervous system and comparable to such a group of fibers as the direct cerebellar or fillet tracts of that system."

Thus far we have trodden the solid ground of fact. It remains to inquire whether our result is only a curious anomaly of vision or whether so striking a circumstance as the constant overestimation of the right half of the field of vision has not resulted in some equally marked modification in behavior. Believing as we do that there can be no constant peculiarity of sensation without some equally constant form of motor response, there are many considerations which lead one to think of the predominant use of the right hand by 98 per cent. of the human species as a consequence of the differ-

ence in space sense between the right and left halves of the retinas. (1) Those highly specialized unilateral movements of the right hand and arm, which characterize righthandedness receive their innervation from the motor region of the left hemisphere of the cerebrum. In proof of this proposition one may cite (*a*) the heterolateral movements of the limbs which are elicited by stimulation of the motor region of the cortex cerebri of dogs and apes. (*b*) The occurrence of lesions in that hemisphere of the brain which is heterolateral to the side of the body upon which a hemiplegia occurs. (*c*) The decussation of the pyramidal tracts which can be demonstrated by gross and microscopic methods. (2) From the law of the forward direction[1] of the nerve impulse by virtue of which the nerve impulse flows only from afferent or associative to efferent neurones, it follows that the nerve impulse which innervates the pyramidal cells for the hand and arm must originate in some afferent system of neurones. The experimental proof of this law rests upon the fact known as the Bell-Magendie Law,[2] that stimulation of the central end of the cut motor root of a spinal nerve produces no motor effect. Indeed the Bell-Magendie law is only a special case of the more general law of forward direction. Psychologically the law means that there can be no motor expression without some form of sensory impression. (3) It follows from our second consideration that such a conspicuous example of motor bilateral asymmetry as righthandedness must have its cause in an equally conspicuous example of sensory bilateral asymmetry. This sensory bilateral asymmetry exists in the difference in space sense between the right and left corresponding halves of the retinas. In view of the unique mode of origin of the optic nerve and the fact that it is to be considered as a conducting tract within the central nervous system similar to the fillets, the circumstance that the left corresponding halves of the two retinas are connected with the left hemisphere directly and exclusively as is abundantly proven by hemianopsia and the histological tracing of con-

[1] James, 'Prin. of Psych.,' Vol. II., 581.

[2] Sherrington, 'The Integrative Action of the Nervous System,' 38.

duction pathways, is almost conclusive proof that the afferent system of neurones from the left corresponding halves of the retinas is the source of the current of innervation which eventually produces movements of the right hand and arm. This view is rendered the more plausible when one considers the importance of the eyes as organs for initiating manual responses and also the increasing importance of the coöperation of the eyes and the hand as the education of an infant proceeds. One would doubtless be well within safe limits in saying that in the first years of life fully 90 per cent. of all movements not instinctive are made in response to visual stimuli. Furthermore the control of all exact and refined movements, by the eyes is unremitting especially during the formative periods of such responses. All the more then would one naturally look to the eyes for the initial cause of so marked a motor phenomenon as righthandedness. (4) The manner in which such a sensory difference might operate to cause righthandedness, is easy to conceive. Let it be supposed that an infant is born with a numerical excess[1] of retinal elements in the left corresponding halves of the two retinas. In consequence of this numerical excess over the non-corresponding halves, those objects the retinal images of which are formed upon the left halves of the retinas appear large. It has been shown by Raehlmann[2] that the periphery of retina does not attain functional maturity to an extent that objects are noticed when imaged upon it until about the fifth month after birth. According to the observations of Baldwin[3] and those made more recently by Mrs. Woolley[4] a decided preference for the right hand evinced itself in the

[1] We suggest a numerical disparity as perhaps the most obvious cause of the difference in space sense. An assiduous search through the literature has failed to bring to light any determination bearing directly upon this point. Counts and estimates have been made, to be sure, of the retinal elements per unit area of the macular and peripheral regions. But so far as we have been able to ascertain, no direct comparison has been made of two symmetrical non-corresponding areas of equal size. Needless to say in view of the results of our experiments such a study is greatly to be desiderated.

[2] *Zeitschrift für Psychologie und Physiologie der Sinnesorgane*, Vol. 2, p. 53.

[3] 'Mental Development, Methods and Processes,' 64.

[4] 'The Development of Righthandedness in a Normal Infant,' Helen Thompson Woolley, Psychological Review, XVII., 37.

seventh month. We believe that the latter phenomenon depends upon the former. If an infant at the time that the periphery of its retina were maturing, were confronted by two objects of approximately equal size, both lying in the horizontal plane at the same distance from the eyes, the right object would form its retinal images upon the left corresponding halves of the retinas, while the left object would form its retinal images upon the right corresponding halves of the retinas. The right object by appearing larger would make a stronger claim upon attention. Once attended to, that reflex connection between the periphery of the retina and the rectus internus of the right, and rectus externus of the left eye would move the eyes until the object lay in the direct regard of the foveas. Following the eye movements, the reaching movements of the arm and hand of the right side naturally ensue. The hand thus favored gains in skill and comes naturally to be used in all movements requiring superior precision and control. Finally, practice and habit make the reaction inveterate.

The theory here outlined was first published three years ago. Since that time, two experimental studies have appeared which corroborate strongly the conclusions which have been arrived at in this paper. Woolley[1] made a series of observations upon an infant beginning in the middle of the seventh month of its life. Colored discs and a wooden square and circle were placed before the infant at distances within easy reach. The number of times the right or left object was reached for and the hand by which the movement was made, were recorded. The results may be stated in the words of the author. "In recording which of the discs or forms was taken, it soon became apparent that regardless of the hand used, the right hand position possessed an independent attraction for the child. In the selection of the colors, where the right hand was used 206 times and the left 194, and both 68, the right hand *position* (italics in the original) was selected 285 times, and the left 183. The difference is even more marked in the case of the square and the circle, where the material itself was indifferent. Out of

[1] *Loc. cit.*

70 choices, 56 were for the right hand position and only 14 for the left. . . . I must confess myself at loss for an explanation for this preference for the right hand position. It could not have had to do with the child's posture, or her relation to the light, for those factors were varied from day to day. The tests were not all made in the same room, and the child sat sometimes in a high chair, sometimes on a couch, and sometimes on the floor. The only requirement was that she should be in an easy position, with both arms free to move. The only suggestion which seemed at all probable was that it might be conditioned by her eyes, though as far as I could judge, or could test them her eyes seemed not only normal, but unusually good. They were very well coördinated at an early age, and gave more evidence of distant seeing than is usual at so young an age. So far as their application to theory is concerned, the tests are only one more proof of the already accepted view that righthandedness must be a normal part of physiological development, not a phenomenon explicable by training. The preference for the right-hand position, in excess of that for the right hand (the author means the right object was sometimes reached for and grasped by the left hand) suggests a query as to whether the eyes could play a rôle in the development of right handedness, but the query is scarcely worth making so long as the observation is an isolated one."[1] It would be difficult to imagine stronger corroborative evidence that the development of righthandedness depends upon the eyes. It is not shown, however, that the reason for the preference of the right *position* apart from the nature of the object, was due to a difference of the space sense of the peripheries of the retinas. The confirmation of the requirements of the theory is the more striking in view of the fact that the authoress was unaware that such a theory had been suggested.

Poschoga[2] determined the absolute space limen for eight radii of the field of vision and for two parallels of latitude

[1] *Loc. cit.*, p. 40.

[2] 'Die sukzessive und simultane Raumschwelle im indirekten Sehen,' Nicolai Poschoga, *Wundt's Psych. Studien*, VI., 384.

(22.5°) and (45°). The radii were 45° apart. Those points in the field of vision were investigated which lay at the intersections of the radii and the parallels of latitude. Using these points as centers, the limen was determined both by the simultaneous and successive presentation of stimuli for vertical, horizontal and two oblique dimensions. The limina are somewhat different in the two cases. In both however marked differences exist between the threshold in the right and left halves

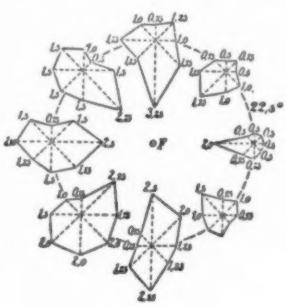


FIG. 12.

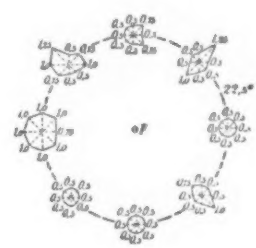


FIG. 13.

of the field of vision. Figs. 12 and 13 show Poschoga's limina for the 22.5 degree parallel.

Only the results obtained by Poschoga at 22.5 degrees are taken into consideration by the authors. They feel from their own observations that reliable readings can not be made at forty-five degrees from the fixation point. Poschoga indeed admits as much himself. He says:[1] "Auf der nasalen Seite ist nämlich die Deutlichkeit des Sehens in diesen ausseren Regionen so gering, dass man der Lichtreize nicht direkt von der diffusen Reflexion des Lichtes an dem Nasenrücken zu unterscheiden vermag. Ich habe erst später gewissermassen zufällig festgestellt, dass ich die Lichtquelle selbst bei jenem Punkt nicht mehr sehen konnte. Insofern scheinen die Werte für die Schwellen in diesen äusseren Region der nasalen Seite mehrdeutig zu sein." In the absence of any numerical criterion of the accuracy of his results and with the knowledge of the difficulty of exact observation in the periphery of the field of vision, one feels justified in saying that doubtless

[1] *Loc. cit.*, 409.

Poschoga's comment on his own results at forty-five degrees on the nasal side should be extended to those of the temporal side as well. Although there is considerable discrepancy between the two results in many concrete instances, there is, notwithstanding differences, a very general agreement, in the fact that the limen in the left positions of the field of vision is very much greater than the limen of symmetrical positions in the right half of the field of vision. The authors consider this circumstance but another demonstration of the fact already shown in this paper and elsewhere[1] that objects in the right half of the field of vision are overestimated. This overestimation of the size of an object is due to some anatomical peculiarity of the left corresponding halves of the retina which they acquire by virtue of their connection with the left hemisphere of the brain. A fact analogous to this relationship between a small spatial limen and an increased perception of size is the well-known tactual space illusion which occurs when a pair of compass points separated by 1 cm. are drawn from the ear on one side of the face across the lips to the opposite side of the face. Although the points of the compass trace a pair of parallel lines over the skin, the apparent course of the points is two lines concave above and below the mouth. Similarly, two compass points set at a fixed distance apart and drawn down the volar surface of the forearm upon the palm, seem at first to trace a single line but appear to separate when the palm is reached.[2] There seems therefore to be good grounds for the generalization that in space perception those parts with the finest discrimination of two points are also the parts that give the greatest perception of size. If one compares Poschoga's figures[3] of the limina which are reproduced in Figs. 12 and 13 with Figs. 1 and 2 of Stevens's article[4] on the perception of size by peripheral retina, the extent to which one figure supplements the other becomes very striking. Those positions in the field of vision which show the smallest limen in Poschoga's figures show the greatest overestimation in those of Stevens.

[1] Stevens, 'Peculiarities of Peripheral Vision,' Psych. Rev., XV., 69.
[2] See James, 'Prin.,' II., 141 and 142, for figures showing these illusions.
[3] *Loc. cit.*, pp. 74 and 75.
[4] Fig. 12 is the sukzessivschwellen. Fig. 13 is the simultanschwellen.

Summary of Results

1. With the few exceptions which have been already stated, it may be said that the right half of an extent in the field of vision is overestimated.

2. This overestimation holds true for both right and left eyes.

3. The extent which is overestimated forms its retinal image upon the left corresponding halves of the two retinas.

4. The left corresponding halves of the two retinas are connected exclusively with the left hemisphere of the cerebrum.

5. By reason of the fact of a marked difference in the space sense of the two halves of the retina, those objects in the right half of the field of vision, by appearing larger, attract the visual attention which in turn leads to grasping movements of the right hand. The hand thus favored by earliest experience acquires a special skill which causes it to be used in all manual acts requiring the greatest precision.

DIFFERENCE-SENSIBILITY FOR RATE OF DISCRETE IMPRESSIONS[1]

BY KNIGHT DUNLAP

I. The Problem and the Apparatus

When two regular series of stimuli (strokes of a hammer, or flashes of light, for example), are addressed in succession to a subject, how great must be the difference in the rate of succession of the stimuli in the two series, in order that the subject may perceive that one series is faster than the other?

This question is important *per se*, but it is perhaps of greater importance in its bearings on the acceptance or rejection of certain types of apparatus which may be or may have been provisionally assumed to be suitable for experimental work on rhythm or on some other topic which requires a certain temporal uniformity of stimulation. We can not say how far below the threshold of difference-perception the variations in a given series of stimulations must be in order that the series may be said to be practically uniform, nor can we assert that variations which are above the threshold do or do not render a given series unsuitable for a certain purpose, until we have made further investigations into the effects of these irregularities upon the processes which it is proposed to attack experimentally with the aid of such series. Before, however, any conclusions in regard to points of this kind are possible, we must know approximately the ranges in which the rate-thresholds lie.

In the experiments here reported, I have attempted to determine the rate difference threshold for visual and auditory stimuli, for two standard rates, one a trifle faster than four stimulations per second, and the other a trifle faster than two per second, both when the impressions were rhythmically grouped and when they were not. I have also attempted

[1] From the Psychological Laboratory of the Johns Hopkins University.

in a few cases to compare the rate-threshold with the time-threshold for standard intervals corresponding to the standard rates, and have investigated superficially the effect of intensity of stimulus on the rate-judgment with auditory stimulus. I have in addition carried out one set of experiments with electrical stimulus.

The exact details of the experiments were to a considerable extent determined by instrumental limitations. The principal desiderati in the line of apparatus were: a control-instrument which should be extremely accurate in its period, and at the same time permit rapid and accurate change of its period; and stimulus instruments which should admit of perfect temporal control by the control-instrument, and which should emit stimuli of constant intensity. I found none of these conditions easy of fulfillment.

The most satisfactory control-instrument which I could secure was a weighted-spring vibrator which was constructed for these experiments. Figure 13 gives a side-view of this instrument, omitting some of the details of the switch. Figure 14 gives a view of the switch on a larger scale, looking down from above it. The letters *U*, *C*, *N*, *R*, *F* and *T* on the one figure indicate the same details as the same letters on the other figure. The spring (*V*) is a tempered steel rule, 30 cm. long, 5 mm. wide and 1 mm. thick. This spring is held in a vertical position between the plate (*O*) and the base (*B*). The weight (*W*) is slotted to slide on the rule, and is held in any desired position by the set-screw (*P*). Two weights were used, giving two standards with the variables corresponding. The lever (*L*) of the electric switch projects at right angles to the rule and is so adjusted that it just touches the rule when the latter is at rest, being held in position by the light spring (*S*). The slightest movement of the rule from the position of rest towards (*U*) therefore breaks the contact between the lever and the screw (*J*), and it remains broken until the rule passes the point of rest in the opposite direction. The whole switch may be moved towards or away from the rule (*V*) by loosening the clamp-screw (*H*), allowing the rod (*N*) to slide through the split support (*R*).

The position of the lever (*L*) alone may be changed by adjusting the contact-screw (*J*). The whole key may be moved vertically by loosening the clamp-screw (*C*) which passes through a slot extending almost from top to bottom of the plate (*U*). The tension of the coil spring (*S*) is adjustable by turning the windlass-peg (*T*). The pieces (*E*, *E*) carrying the contact screws (*J*, *K*) are insulated from the frame (*F*), and electric connections were made at (*E*) and (*F*) by binding posts (not shown). The tips of the screws (*J*, *K*) and the portion of the lever (*L*) touching each are platinized. Contact (*K*) was not used in the experiments herein described. The inner ends of the thumb-screw (*D*) and its mate are cupped to receive the coned ends of the pivot to which the lever (*L*) is fastened. The lever and pivot shaft together weigh 1.7 grams, of which about two thirds is the weight of the shaft. Z, Z, Z indicate lock-nuts. No electric current passes through the rule (*V*); this is an important point.

The rule is set in vibration by pressing it lightly against the stop (*X*), and then releasing it. The pressure is applied to the rule by the finger, opposite (*X*), so that the rule is always flexed in the same way as well as to the same degree. When handled in this way the rule vibrates with a period which is practically constant, and which shows no progressive change during the first fifteen seconds of vibration. But it is essential that the initial amplitude shall be constant and small, or serious variations arise. The initial deflection in the experiments described below was approximately one centimeter.

The vibrations were not absolutely regular, even when all possible precautions were taken. Although there was no progressive variation in the period of the rule during the time for which the vibrations were employed in the experiments (never so long as ten seconds), slight irregular variations occurred occasionally, amounting, with the heavier weight, to from two to three sigma as a maximum (about two thirds of one per cent.). With the lighter weight the variations were so far below one sigma that they were not measurable. The vibrator, in short, seemed sufficiently accurate for the

experiments planned, and is undoubtedly much more accurate than a magnetically driven reed. A weighted reed is as treacherous as the traditional broken one, and will not vibrate uniformly except under uniform conditions.

The settings of the weights for the standard rates were at 25 on the scale of the rule. The settings for the variable were at intervals of two millimeters above and below this mark. The marks on the scale are about 0.15 mm. wide, and the settings could be made with an error of less than the width of a mark, if five seconds were allowed for the setting. It was not found practicable to allow less than five seconds, although the setting was often done in three seconds. The possibilities were thus limited to a standard rate (or time-interval) followed by a variable after a pause of five seconds. Two reeds might be used, one for the standard and one for the variable, with a considerable lessening of the experimenter's labor, but this would introduce the possibility of greater inaccuracies, and hence was not attempted.

The vibrator was standardized, with the switch adjusted exactly as used in the experiments, by means of the Pfeil marker and 250 d.v. fork writing on a drum. The marker was connected in series with the switch, and the timing was from break to break of the circuit, under which condition the Pfeil marker gives almost absolutely accurate records. Some records were also taken by the spark method (using only break-sparks) and these agreed perfectly with the Pfeil records. No account was taken of temperature changes during the course of the experiment, and these changes, although slight, undoubtedly caused some variation in the vibration period of the rule. Since these changes affected standard and variable alike (or nearly so), and were practically equivalent to a shifting of the whole scale up or down, they were of no great consequence.

The sound-source finally selected was made from a Western Union pattern telegraph sounder. It is represented in Figs. 15 and 16. The armature was removed from the sounder, and replaced by a shorter one (*A*). Short pieces of soft iron (*Y*, *Y*) were screwed on to the poles of the magnet

(*M*, *M*); they are in such positions that the armature just moves between them without touching. The ends of the armature and the inner ends of the pole pieces were beveled, to a width of about a millimeter.

When current is allowed to flow through the sounder magnets, the armature (*A*) is drawn down into line with the two pole pieces (*Y*, *Y*), thus depressing the long end of the lever (*G*). This takes place noiselessly, as the armature is checked by the magnet. It is true that the snap of the magnet cores as they are magnetized can be heard if the ear s close to the sounder (even when the armature and lever are entirely removed this is audible), but at the distance at which the subject was placed in the experiments it was not perceptible.

When the current through the magnet is interrupted, the armature and long end of the lever (*G*) are allowed to rise, the short end of the lever being pulled down by the spring (*O*), until the long end strikes against the screw (*I*). This screw is platinum tipped and bears against a platinum plate on the lever. The use of this contact is described below.

From the description, it is perhaps clear that the sounds were produced by the armature-lever striking the screw on the up-stroke, the intensity of the stroke being regulated by the tension of the spring (*O*), and by the adjustment of the screw (*I*). The temporal regularity therefore depends on the break of the current through the magnets, and this is controlled almost absolutely by the vibrator. The make of a current through a magnet coil can not be depended on, if the contacts of the control instrument are of the usual type, since the current does not always rise to its maximum at the same rate.

Variations in the intensity of the current are practically without influence on this sounder, provided the weakest current is sufficient to pull the armature completely down. Theoretically, a sudden change in the current strength should modify the length of the interval in which it occurs, but practically such a change must be relatively large to produce a measurable effect, and moreover, is not apt to occur. A change in the

current from series to series (due for instance to the running down or recharging of the batteries) produces absolutely no effect. In the experiments in which the sounder was used, the current (supplied by chloride accumulators) was kept constant in amperage.

If the sounder is started and stopped by means of a simple switch in the circuit, it is apt to 'limp' on the final stroke and sometimes on the initial stroke. If the circuit is broken while the vibrator switch is closed (while therefore the sounder-lever is down), the lever will be released immediately, giving a stimulus after an interval shorter than the preceding intervals. If the circuit is completed (by the hand switch) a few sigma before the vibrator switch is opened, the sounder lever is not pulled completely down before being released, and the first stroke is weaker than the succeeding strokes, while the first interval is unduly long. The initial 'limp' occurs very seldom, as might be expected from the conditions which produce it. The terminal 'limp,' however, is a serious matter, occurring frequently if a hand switch is employed, and disturbing the subject's judgment when the limp occurs at the end of the standard series.

In order to eliminate the terminal 'limp,' the sounder-circuit was made and broken by a Western Union relay. The magnet-windings of the relay were connected in series with the contact between the lever (*G*) and the screw (*I*) of the sounder, and with a hand-switch. The contacts of the relay were so connected in the circuit through sounder-magnet and vibrator switch that when the armature lever of the relay was released by the relay magnet, it completed the sounder circuit. The sounder circuit therefore was broken by completing the relay circuit, and this could be completed only when the sounder lever was at the top of its stroke. If the hand switch in the relay circuit was closed while the sounder lever was being held down, the sounder circuit was broken immediately after the next up stroke.

As a visual stimulus the flash of a helium tube was used. The vibrator switch was connected in series with the primary of a small induction coil and with the magnet of an automatic

cut-out, which shunted the make spark around the helium tube and allowed the break spark to pass through it.

The stimulators (sounder and helium tube) were set up in one room, and the operating mechanism was installed in another room separated from the first by a hallway. In the auditory experiments the subject sat about four feet from the sounder, back to it. The helium tube was suspended, in a box open at the bottom, over a table in front of the subject. A black cloth was placed on the table, and upon this a piece of white paper three by five inches, with its long axis horizontal and its short axis inclined at an angle of about thirty degrees from the line of regard. The paper was approximately three feet from the subject's eyes. In the visual experiments the room was partially darkened, and the periodic illumination of the piece of paper came out vividly.

In order that the experimenter might hear the auditory stimulus, a microphone was fastened to a board upon which the sounder was set. The microphone was a rude affair, constructed of two electric light carbons, but worked very well. It connected with a telephone receiver suspended near the ear of the experimenter. It was necessary that the experimenter should hear the auditory stimulations in the 'time' series, in which but two stimulations were given in succession. The microphone also served a useful purpose in the experiments on intensity-changes; in these experiments the subject sat in the experimenter's room and listened to the telephone, instead of to the sounder direct, as in the other auditory experiments.

A telegraph key was placed on a small table at the right hand of the subject. This key was connected with a sounder in the experimenter's room, and by means thereof the subject communicated his judgments to the experimenter in a conventional code.

The current which operated the relay circuit, that which operated the microphone, and that which operated the telegraph system was drawn from the lighting circuit, through appropriate resistances and reduced to proper voltages by shunt resistances.

2. The Methods of the Experiments

There were two main types of experiments. In experiments of the first type a series of stimulations was given at one of the standard rates during a period of approximately five seconds. Then followed a five seconds pause, during which the weight of the vibrator was set for one of the variable rates, and stimulations at this rate were given for five seconds. The subject was required to determine whether the variable series was faster than, slower than, or equal to the rate of the standard. (No distinction was made between judgments of 'equal' and judgments of 'not different.')

In some of the experiments both standard and variable series were auditory. In other cases both were visual. In experiments of a third sort one series (standard or variable) was visual and the other was auditory. In one set of experiments electric stimuli were used.

In most cases the intensity of the stimuli in the standard and variable series was the same. In certain sets, however, the intensity of the variable was greater or less than that of the standard. These were the sets in which the subject listened to the telephone (microphone) instead of to the sounder. By means of a Morse key closing a shunt circuit with appropriate resistance a part of the current flowing through the microphone could be diverted from the telephone receiver, thus decreasing the loudness of the telephone noise. The subject, during these intensity-experiments, sat at a distance of about four feet from the table on which were the vibrator and accessories, with his back towards it, and the telephone receiver was supported at a distance of about six inches from his left ear. The only feature of the operation of the apparatus (except the microphone) which was audible to the subject was the faint click of the relay as it made and broke the sounder circuit. The sounder of course was not directly audible.

There was a marked difference between the two intensities of sound which were used. The three subjects who served in this part of the experiment each estimated the louder sound to be about twice as loud as the weaker ones, on the average.

No attempt was made to measure the intensities physically (this measurement is impossible for such sounds[1]), but the currents which flowed through the telephone receiver when the microphone was at rest were kept constant, the amperage for the weaker series being exactly half that used for the stronger.

The series of stimulations in the intensity experiments departed from uniformity in several ways. In the first place the sounds were prolonged, each one lasting nearly to the beginning of the next one; but the duration perceptibly varied. In the second place, the sounds, as wholes, varied perceptibly in intensity, although the variations within any series were small as compared with the differences between the loud and weak series. In spite of these irregularities there was a definite regularity in the series, due, no doubt, to the equality of the intervals from the beginning of one sound to the beginning of the next.

In some of the experiments on rate-comparison, the rates were compared without grouping of the impressions. In other experiments the subjects grouped the impressions in twos, threes, fours, or sixes.

In experiments of the second type, a standard time-interval marked off by two clicks of the sounder was compared with a variable interval marked off in the same way. In some cases the standard interval was given but once, and the variable also was given but once. In other cases each was given three times, the time from the beginning of the first presentation to the end of the third being approximately

[1] The amplitudes of vibrations of the telephone diaphragm might be measured, as recommended by Pillsbury, Psychol. Rev. Monog. Suppl., 13: 1 (53), 5–20, but this procedure would be of little assistance. Even if the diaphragm were mounted without enclosed air-space on either side of it, and were vibrating in a strictly sinusoidal way, the relative amplitudes of excursion of any single point on the diaphragm would not represent the relative amplitudes of the air waves propagated from the diaphragm. As the telephone diaphragms are actually mounted, the amplitude of vibration of the center of a given diaphragm does not even determine the amplitude of the wave it is propagating; the amplitude of the wave may be increased or decreased enormously without altering materially the limits of the diaphragm vibration, or the form of the air-wave. Finally, and not least in importance, the wave-form changes materially when heavier current is used, and the relative amplitudes of two air waves of different forms do not indicate the relative total energy of the waves.

five seconds. In either case, five seconds pause occurred between the standard and the variable, as in the rate experiments. A warning signal was given two seconds before the beginning of the standard, the signal being the extinguishing of an electric light which illuminated the small table at the subject's right hand.

In experiments of both types, the subjects were given the information that the interval between the standard and the variable was always approximately the same, but that the duration of the standard and the variable series in the rate experiments were only uniform in the average, being sometimes shorter, and sometimes longer than the nominal five seconds duration. (Except in the case of the slower standard with six-grouping. In this case the standard always consisted of twelve stimulations, and the variable of twelve or more.) The subject therefore understood that counting the stimulations would not help in the comparison of the series, and the testimony of all of the subjects was that they were entirely undisturbed by and inattentive to the numerical factor.

The experimenter controlled the durations of the rate series and of the intervening pauses while watching the second-hand of a watch placed conveniently close to the vibrator. The finger movements for discontinuing the standard and for commencing the variable were made each as the second hand crossed a five-second mark; the extreme limits of variation of the pause were therefore one stimulus-period longer and shorter than the nominal five seconds. The finger-movements for beginning the standard and for discontinuing the variable were made within limits of one second before and after the five-second marks.

The time-series were given by closing the switch and then opening it as soon as the first stimulus was heard in the telephone. In this way single pairs of stimuli were given. The pause between standard and variable was perhaps a little more variable than in the rate series; but it was not noticeably so in terms of the movement of the second-hand.

The two standard rates used were given by setting the

weight (the light one in one case and the heavy one in the other) at the 25 mark on the rule (vibrator). The actual interval between successive breaks of the switch contact was 232 sigma with the one weight, and 435.5 sigma with the other. The variables were determined by setting the weight at even-millimeter marks above and below the standard (*i. e.*, 24.8, 24.6, 24.4, etc., descending; and 25.2, 25.4, 25.6, etc., ascending). The difference in period between the rates at successive points in this scale was 2.75 sigma for the 232 standard and 7.4 for the 435.5 standard. To be more precise: the differences lay between 2.5 and 3 sigma for the one standard, and 7.25 and 7.75 for the other standard, averaging 2.75 and 7.4 respectively. I did not attempt to measure closer than 0.5 sigma in any case. Throughout the range of the scale which was used the 2 mm. step gave the same period-difference, within the limit of the measurements; that is, there were no detectable variations, although at a greater distance from the 25 mark the same step (2 mm.) gave a different period-difference.

The order in which the variables were given in any series was determined by chance, and the method[1] of determining the order was fully explained to each subject. The number corresponding to each rate was written on each of eight playing cards of the same denomination. The standard, for example, was represented by the queen. Playing cards were used because of their easy manipulation, and the use of one denomination for one rate made easy the sorting of the cards when less than the full number were used.

For the series in which there were but five rates all the cards for each rate were ordinarily used. In the longer series, only four of each denomination were used. Occasionally, some other number of cards was used, to make up a series to

[1] I describe this method in detail because it is the method of right and wrong cases, with the essential features of the classic method left out — Hamlet with the mad prince omitted. I do not know of any name by which to designate it at present. 'Method of constant stimuli' applies as well to 'method of minimal change' as to this method, and 'method of right and wrong cases' implies the mathematical treatment which was included in this method by the psychophysicists, and which I believe is entirely out of place in the treatment of psychological data of any intrinsic value.

bring a set up to the number of judgments desired, or for cases in which only a part of an experiment period was devoted to a set, as in sets o-IV. to o-VII. (see below). The normal series with eight variable rates therefore consisted of 32 variables, and the series with five rates consisted of 40 variables.

The cards were thoroughly shuffled, and the order of the variables was then drawn off in a typewritten column on a sheet of paper which was used in the experiment. The judgments were recorded on this sheet in a second column, parallel to the column of variables. On another part of the sheet the variable rates employed appeared in a short column in order of their position in the scale. After the experiment was finished the judgments were posted to this column, and posted from this to the sheet including the records of the whole set. By observing this routine all possibilities of errors in the conduct or the record of the experiment series were avoided.

The subject, being conversant with the method of making out the form-sheet for the experiments, understood that there were a number of appearances of each variable rate, and that they might appear in any order. He was not told the exact number of variable rates employed in any set. He was told that some of the variables were exactly the same in rate as the standard, and that the number of variables slower than the standard might be greater or less than the number faster than the standard. Under these conditions the subjects were able to give judgments which seemed absolutely unbiased.

In most cases, the stimuli series were given with fifteen seconds interval between the variable of one pair and the standard of the next. In some cases the interval was twenty seconds or longer, and in a few cases it was only ten seconds. To run through an experiment series of 32 pairs required usually about twenty or twenty-five minutes. In cases in which two experiment series were taken in one day, from five to fifteen minutes rest was allowed the subject between the two series. Two experiment series could be taken in this way without appreciable jading of the subject.

When a new set was begun on a subject, no records were made on the first day; the work on this day was simply devoted to familiarizing the subject with the conditions of the experiment, and to finding out the range of variables which it seemed advisable to use under those conditions. In such work the formal plan of experimentation was not adhered to, but the variables were selected currently. The one exception to the above statement was in the case of set I-III. (Subj. *MW*), which were under exactly the same conditions as the preceding series and hence called for no practice.

3. The Results of the Experiments

The results of forty-one sets are included in the table, and the data from 35 sets are schematically presented in the graphs of Figs. 1 to 12. We must consider now the method of elaborating the data.

Each set of experiments brought out a number of judgments of the variable rates employed in the set, these judgments being distributed in the categories of 'longer,' 'equal' and 'shorter' for the time experiments, and 'slower,' 'equal' and 'faster' for the rate experiments. We may designate the judgments of 'longer' and 'slower' as *minus*, and the judgments of 'shorter' and 'faster' as *plus*. The problem is to present these results in such shape that ready comparison of the sets will be possible.

We might plot the error-curve (or a graph corresponding to it) by the orthodox method of dividing the judgments of 'equal' equally between the categories of 'plus' and 'minus,' and designating the one of these categories which contains the fewer number of judgments for a given variable the category of 'error' for that variable. The error method has absolutely no advantages over a simpler method in the way of clearness or significance in the presentation of the data we are considering, and is in the opinion of the writer decidedly objectionable in psychological work. We shall therefore turn to the simpler and more significant method.

That which interests us in the total group of judgments on any of the variables is *the percentage of cases in which it*

is discriminated from the standard. This percentage may be computed by finding the difference between the number of judgments of 'plus,' and the number of judgments of 'minus,' and reducing the difference to per cent. of the total number of judgments. The judgments of 'equal' are precisely judgments of 'no discrimination,' and an equal number of 'plus' and 'minus' judgments is the virtual equivalent of twice the number of 'equal' judgments. The percentages of discriminations are given in the table, with the signs (*plus* and *minus*), to indicate the direction of discrimination. The graphs of Figs. 1 to 11 are drawn by laying off distances on the X-axis which correspond to the variables, and erecting at the point corresponding to a given variable the ordinate of length proportionate to the percentage of discrimination for that variable. The variable which is equal to the standard is at the intersection of the X-axis with the prolongation of the two short vertical lines (these lines therefore mark the Y-axis), and the abscissas of the shorter (faster) variables are indicated on the minus side thereof, the longer (slower) variables being laid off on the plus side of the origin. The horizontal lines mark the loci of the points whose ordinates are 50 and 100 per cent. of discriminations, those above the X-axis being discriminations as 'shorter' or 'faster' (*plus* in the table), and those below the axis being discriminations as 'longer' or 'slower' (*minus* in the table).[1]

Fifty per cent. of discrimination is the conventional 'threshold.' This value corresponds to seventy-five per cent. of 'right' judgments (twenty-five per cent. 'error') in the error method: for when $p - m = (p + e + m)/2$, $p + e/2 = 3(m + e/2)$ or $4(m + e/2) = p + e + m$.

Figure 12 reproduces a graph plotted by the method above described, and the graph plotted by the error method from the same data (the data of set 7-III.).

[1] There is obviously an inconsistency in the choice of the plus and minus directions in the figures. Since the variables slower than the standard are plotted on the plus of the Y-axis, the discriminations of the variables as slower should have been plotted on the plus side of the X-axis: the graphs then would run upward from left to right, instead of downward. Inasmuch as the figures were wrongly drawn before this was written, and seem as intelligible in one position as in the other, the text was simply changed to agree with the figures.

Table of Percentages of Discriminations

Subj.	*MW*	*MW*	*MW*	*CW*	*CW*	*CW*	*CW*	*CW*	*CW*
Set.	1-I.	1-II.	1-III.	3-III.	3-II.	3-I.	4-II.	4-I.	4-III.
Mode.	Aud.	Aud.	Aud.	Aud.	Aud.	Aud.	Aud.	Aud.	Aud.
Type.	Rate	T-s	T-s	Rate	T-t	T-s	Rate	T-s	3's
Std.	232	232	232	232	232	232	435.5	435.5	435.5
No.	25	25	25	44	40	45	40	50	40
−4	100	80	84	97.7	85	95.5	100		
−3	100	92	96	97.7	77.5	82.2	97.5	84	
−2	96	68	40	88.6	57.5	64.4	85	82	97.5
−1	52	48	56	77.2	37.5	22.2	45	58	82.5
0	4	8	−12	11.3	− 5	2.2	17.5	36	40
1	36	28	44	13.6	17.5	13.3	−25	24	− 40
2	− 72	−72	−28	−45.4	− 25	− 17.7	−65	2	− 92.5
3	−100	−56	−56	−81.8	− 25	− 57.7	−95	−34	
4	− 96	−76	−80	−95.4	− 27.5	− 64.4	−92.2	−46	
5					− 45			−56	
6					− 57.5			−78	

Subj.	*CW*	*CW*	*CW*	*CW*	*CW*	*CW*	*CW*	*CW*	*CW*
Set.	0-I.	0-II.	0-III.	0-IV.	0-V.	0-VI.	0-VII.	3-IV.	2-I.
Mode.	Aud.	Aud.	Aud.	Aud.	Aud.	Aud.	Aud.	Aud.	Aud.
Type.	4's	6's	2's	2's	2's	4's	6's	[1]	S-W,3's
Std.	435.5	435.5	435.5	232	23w	232	232	232	232
No.	40	30	40	20	20	20	20	60	25
−2	92.5	100	100	100	100	100	95	100	96
−1	80	93.3	97.5	90	70	80	90	80	60
0	35	23.3	35	5	40	45	50	30	20
1	27.5	23.3	27.5	30	30	40	25	33.3	32
2	80	73.3	90	85	95	100	85	93.3	72

Subj.	*CW*	*GW*	*GW*	*GW*	*GW*	*GW*	*GW*	*GW*	*SW*
Set.	2-II.	5-I.	5-II.	5-III.	5-IV.	5-V.	6-I.	6-II.	9-III.
Mode.	Aud.	Aud.	Aud.	Vis.	A.-V.	V-A.	Aud.	Aud.	Aud.
Type.	W-s, 3's	T	Rate	Rate	Rate	Rate	S-W	W-S.	Rate
Std.	232	435.5	435.5	435.5	435.5	435.5	435.5	435.5	232
No.	25	40	40	30	40	40	25	25	40
−6					82.5				
−4					42.5	100			100
−3		75		40					92.5
−2	92	65	100	45	− 15	92.2	96	100	77.5
−1	76	50	65	12.5			44	72	35
0	24	42.5	20	−27.5	− 70	− 12.5	−12	32	20
1	− 32	2.5	−42.5	−15			−64	− 4	− 57.5
2	− 80	−32.5	−90	−37.5	− 97.5	− 85	−96	−52	− 87.5
3		−37.5	−95	−87.5					−100
4		−50			−100	−100			−100
5		−77.5							
6		−57.5							

Explanation of the Table

The data from each set are summarized in a short column. Reading from the top downwards, the first line gives the initials of the subject, and the second line the distinguishing

[1] This set is merely the sum of sets 0-IV., 0-V. and 0-VI.

Subj.	*SW*	*SW*	*SW*	*SW*	*SW*	*SW*	*SW*	*SW*	*SW*
Set.	9-II.	9-I.	7-I.	7-II.	8-II.	7-III.	8-I.	8-IV.	8-III.
Mode.	Aud.	Aud.	Aud.	Aud.	Aud.	Aud.	Vis.	A.-V.	V.-A.
Type.	T-t	T-s	T-s	Rate	2's	4's	3's	3's	3's
Std.	232	232	435.5	435.5	435.5	435.5	435.5	435.5	435.5
No.	40	40	24	40	40	40	40	25	40
−7								80	
−6								68	
−5								36	
−4	77.5	85					77.5	24	
−3	62.5	82.5	87.5	100			−55	−24	
−2	50	32.5	58.3	80	92.5	95	52.5	−24	100
−1	2.5	35	12.5	−10	30	37.5	30	−60	92.5
0	27.5	7.5	37.5	22.5	47.5	35	12.5	68	60
+1	47.5	55	12.5	80	90	97.5	37.5	92	12.5
+2	35	35	20.8	92.5	100	100	55		42.5
+3	77.5	70	62.5	100			72.5		95
+4	72.5	65	66.6						
+5	96.4		83.3						
+6	96.4		87.5						

Subj	*GD*	*GD*	*GD*	*GD*	*GD*	*GD*			
Set.	10-I.	10-II.	11-III.	11-I.	11-II.	10-III.			
Mode.	Aud.	Aud	Vis.	Aud.	Aud.	Electr.			
Type.	6's	4's	4's	S-W, 4's	W-S, 4's	Rate			
Std.	232	232	232	232	232	232			
No.	32	40	16	40	40	25			
−3						32			
−2	87.5	82.5	80	67.5	90				
−1	15.6	32.5	40	22.5	80				
0	6.2	17.5	20	25	27.5	8			
+1	56.2	77.5	13.3	65	35				
+2	81.2	92.5	26.6	95	85				
+3			20			28			
+4			6						
+5			24						
+6			18						
+7			48						

number of the set. The numbers correspond with those of the graphs in Figs. 1–11. For example, 3-III. indicates that the data of that column are those from which Graph III. of Fig. 3 is based. Sets not represented in the figures are given the number 0. The third line gives the mode of the experiment. 'Aud.,' 'Vis.,' and 'Electr.' indicate that the stimuli were auditory, visual, or electrical, respectively. 'A.–V.' indicates that the standard was auditory, and the variable visual. 'V.–A.' indicates the converse (visual standard and auditory variable). The fourth line gives the type of the experiments. 'T–s' (for Time, single) indicates

that each judgment was the comparison of the interval between a standard pair of stimuli, with the interval between a variable pair. 'T–t' (Time, triple), indicates a similar comparison of a standard repeated three times with a thrice repeated variable. 'Rate' indicates the comparison of two series of stimuli (determination whether the variable is faster, or slower, or equal to, the standard), without rhythmic grouping. '2's,' '3's,' and '4's' indicate rate judgments when the impressions are grouped rhythmically in twos, threes, and fours, respectively.

The fifth line gives the standard interval or rate, in terms of the interval between the beginning of one stimulus and the beginning of the next, expressed in sigma. The sixth line gives the number of judgments on each of the variables of the set: in set 1-I., for example, there were 25 judgments on each of nine variables—175 in all.

The variables are indicated by the numbers at the left of each of the lines after the sixth. '0' indicates the variable equal to the standard, '– 1' indicates the next shorter (or faster) variable, '1' the next longer (or slower) value, and so on. To find the actual value of the variable on which the judgments in any line are based, multiply the number at the left of the line by 2.75 for the 232 standard, and by 7.4 for the 435.5 standard, and add the result to the standard.

In the case of each subject, the sets are inserted in the table in the order in which they were taken. In nearly every case one set was completed before the next set was commenced (the subject being given a period of practice under the new conditions, without record of judgments, as described in §2 above). The exceptions are sets 0-IV. to 0-VII., 2-I. and 2-II., and 11-I. and 11-II. All four of the 0-sets were carried on concurrently, as were both of the 2-sets and both of the 11-sets, a certain portion of each of several successive periods being given up to each of the four (or two) sets.

4. Introspection and Behavior of the Subjects

Three of the subjects were freshmen, one (*GW*) a graduate student, and the fifth (*MW*) a woman. Very little intro-

spection was required from them, except on the points of their instructions and attention.

GW inclined to the opinion that the differences were largely 'qualitative.' In some cases they seemed purely qualitative, and in others (in certain time-series) partly intensive. In the latter case, the essential difference between two time intervals seemed very like the difference between two 'physical strains,' of which one was more severe. (This subject was at the time reading Bergson's 'Time and Free-will').

All subjects based the rate judgments on the whole of the standard series and the first part of the variable series. In most cases the judgment was made before the end of the variable. Toward the end of the investigation, the men were requested to telegraph their judgments as soon as made, instead of waiting for the end of the series. Under these conditions, the signals were in most cases received by the experimenter about a second before the end of the variable. Very seldom was a judgment signaled after the end of the series.

CW and *SW* felt more certain of the judgments of 'faster' than of those of 'slower.' *SW*, on the other hand, found it easier to detect the slower than to detect the faster rates; or, as he expressed it, to detect the *ritard* than the *accelerando.*

All subjects declared that the grouping in twos, threes, and fours was easy and natural; in threes and fours perhaps most easy, in sixes slightly less so. In sets 2-I., 2-II., 8-III., 8-IV., 8-I., 11-I., 11-II., and 11-III., the subjects were instructed to group in the way which seemed to them most natural.

SW grouped at times by 'counting mentally,' and was conscious of no movements, even of the vocal organs. At other times, he did not seem to count; could not tell what formed the groups, although they were distinct. *CW* also counted the groups. At first there was a tendency to move foot at each accent, although he did not think the foot actually moved. This persisted only for a day or two. Then he felt a slight tongue movement, or impulse to movement, in counting; this also soon disappeared, and no movements

were detected or impulses during the greater part of the work with grouped series. *GD* was uncertain in his introspection. He was not sure that he counted, in many cases, although he did count sometimes. He thought there was no muscular activity connected with the counting or grouping.

In the visual series, *GW* and *GD* gazed at a fixation point approximately 25 degrees to the left of the surface illuminated by the stimulus. This fixation mark was a square of white paper on a black ground, and was dimly visible in the partially darkened room. *SW* gazed part of the time at the stimulus area, and part of the time to the left. Several series were taken on *CW*, but the experiment was discontinued because he found it very disagreeable, and judgments difficult. He said that a continuance of the experiment would be positively insupportable. The other men found the visual experiments less trying than the auditory, and the two who tried grouping found the groups as distinct and natural as with the auditory stimulus.

CW noticed that the visual series 'speeded up,' *i. e.*, apparently went faster towards the middle and end of the series than at the beginning. *SW* at first noticed that the series sometimes increased in apparent rate, and sometimes decreased, but later did not notice these changes. *GW* found very definitely that the apparent rate of a series might change in either direction, if the eye moved, but that when the eye remained motionless (as nearly as he could tell), that the change did not occur.

GW noticed that the slower of two visual series seemed to have more contrast; that is, that the change from the illumination during the flash to the dark interval following, and *vice versa*, was greater. He was inclined to think that his judgments were based on this feature of the series, but was not certain on this point.

5. Remarks on the Results of the Experiment

An examination of the figures shows that the sensibility for rate differences is more acute than the sensibility for time differences, at least under the conditions of the experiment.

This fact is expressed in the greater steepness and greater regularity of the graphs for rate discrimination, as compared with the graphs for time discrimination. Not only does a certain difference between standard and variable give a larger percentage of discriminations in the rate series than in the time series, for all ranges of difference up to those which give 100 per cent. of discrimination in the time series, but also the judgments of rate difference are so regular that sets of from twenty to forty judgments give a very smooth graph (showing that the number of judgments to a set were practically sufficient), whereas even where the time-set ran over forty judgments to a variable, the graph is irregular, not to say erratic.

These differences favor the supposition that the rate-judgment is not essentially a judgment of the interval between stimulations. It can hardly be claimed that the advantage in the rate-judgments was due to the repetition of the time-interval providing a better basis for the time-judgment, for the series with triple presentation of standard and variable (3-II. and 9-II.) do not give results differing essentially from the results in the corresponding sets with but one presentation (3-I., 9-I.).

We have implied that the irregularity in the graphs for the time-experiments indicates merely an insufficiency of judgments in these experiments. This may not be true. The curious way in which graphs I. and II. of Fig. 3, and I. and II. of Fig. 9 correspond in the irregularity of their lower courses, is certainly remarkable. Graphs II. and III. of Fig. 1 suggest the same sort of correspondence, although the kink in III. is placed higher than the kink in II. This may be a practice effect, as set III. was taken after set II., and under the same conditions, but it seems hardly likely. In this case, averaging the two sets obliterates the peculiarities in question. In the other two cases, averaging the sets does not produce such an effect. In Fig. 7, Graphs I. and II. have a curious correspondence of irregularities, but it is not well marked.

Rhythmic grouping of the impressions gave in every case

a more acute difference sensibility, as compared with the corresponding cases in which there was no grouping (compare III. and IV. of Fig. 3; II. and III. of Fig. 4; II. and III. of Fig. 7). Although the increase in acuteness is slight, the fact that it uniformly occurs seems important, since it is out of harmony with the supposition that rhythm perception is essentially a matter of time perception, and fits in with the theories which explain rhythm as a periodicity in consciousness. We may well suppose that if the consciousness-period (whether the succession of specious presents or of attention-waves) be adapted to one rate of stimulation (the standard), a second rate (the variable) will not fit in with that period, and if it differs sufficiently from the standard the incongruity may be perceived, independently of any difference in the perceptible rates of succession of the single impressions, and of any difference in the perceptible time-lengths of the groups.

The approximate threshold values in the results of the auditory experiments are quite low. In every case the upper and lower threshold are both included within the limits of three steps in the scale of variables. If the upper threshold is between − 1 and − 2, the lower is between 0 and 1; if the lower is between 1 and 2, the upper is between 0 and − 1.

One step in the scale is 1.18 per cent. of the 232 standard, and 1.67 per cent. of the 435.5 standard. The difference thresholds, therefore, for the 232 standard are all *below 2 per cent.*, and for the 435.5 standard *below 3 per cent.* The total range of no discrimination for the 232 standard is under 3 per cent., and for the 435.5 standard under 4.5 per cent.

The constant errors are slight in the auditory experiments, and are in both directions; we should perhaps consider them as mere irregularities in the position of the absolute no-discrimination than as typical constant errors. The fact which we have stated above, that the thresholds are not symmetri-

[1] It is quite possible that in many cases objective time-intervals may be compared by noticing the congruity or the incongruity of one interval with a specious present or a succession of specious presents, and that this may be the most accurate method of comparison in the cases to which it is applicable. The work of the Leipzic experimenters on the time-problem takes on new interest in this connection. Such comparison, although of time-intervals, would not be time-estimation; that is, it would not be the comparison of time or duration contents.

cally placed with regard to the point of actual equality is not so significant as the numbers (0 and 1, 1 and 2) would seem to indicate, as we have taken no account of the closeness of the threshold to one or the other of the steps between which it lies. A scrutiny of the graphs, with regard to the abscissæ of their intersections with the *X*-axis and also with regard to their general courses strengthens the impression that the factor of constant error is insignificant in the sets under consideration.

Several of the graphs, notably those of the time experiments, show indications of a factor which, under the proper circumstances (especially, under the conditions of the method of minimal change), might simulate a constant error. The angle which the upper part of the general course of one of these graphs makes with the *Y*-axis is much sharper than the corresponding angle for lower course. This peculiarity is especially noticeable in 3-II., 5-I., and 7-I., and is grotesquely exaggerated in the graph of one of the visual sets (11-III.). We may reasonably suspect that the comparison of a standard with a succeeding longer (or slower) variable is more difficult than the comparison of the same standard with a shorter (or faster) variable.

The results of the visual experiments show that the rate difference sensibility is less acute for the visual conditions than for the auditory. The single electrical series, with only three variables, does not offer sufficient basis for any inference.

The two pairs of sets with standard of one mode and variable of the other (8-II. and 8-III., 5-IV. and 5-V.) give results which are unmistakable. The visual series seem slower than auditory series of the same actual rates. This fact should be considered in connection with the results of the auditory series with two intensities (2-I. and 2-II., 6-I. and 6-II., 11-I. and 11-II.).

In two cases, the series with loud sounds seemed to be faster in rate than the series with weak sounds. In the third case there was practically no difference in the apparent rates with the two intensities. This is what we might expect in ungrouped series, from the converse effect of rate on apparent

intensity. We might also expect that grouping the stimulation impressions should in some cases neutralize the effect of the intensity on the apparent rate. The explanation usually given for the effect of rate on apparent intensity, however, can not be converted into an explanation of these results, unless we are willing to say that the difference in apparent rates of visual and auditory series rests on entirely another basis than that on which rests the difference in the cases of two series of different intensity. If we can admit any inter-modal comparison of sensation intensities, the visual impressions with which I worked were much more intense than were the auditory impressions, and the visual impressions certainly ran together temporally to far greater extent than did the auditory impressions.

The results of the bi-modal series may be harmonized with those of the bi-intensive series on the basis of strain sensations. The visual series provoked eye-strain in the (successful or unsuccessful) attempt to avoid eye-movements, whereas the perceptible strains in the auditory series were less intense. There was, however, more strain (possibly of the tympanic muscles, but probably of the neck and thoracic muscles) in attending to the weaker auditory impressions than in attending to the stronger. While we may not be willing to definitely espouse this theoretical interpretation of the results, it is nevertheless attractive and promising. Strain sensations are undoubtedly an important (although not the sole) factor in time content, and while it is probable that the estimation of rate rests on grounds which are not identical with the time content, it is also probable that the time factor may modify or even override the direct rate judgment. The time and the rate factors may both be important even when the judgment is based largely on the rhythmic factor or factors. It is possible, for example, that the consciousness-period carried over from one series to the succeeding one may be modified by factors in the second series which affect the rate or time judgment directly and do not affect the rhythmic impression directly.

The rate discrimination is approximately as acute with

the telephone noise, in spite of its irregularities, as with the vastly more uniform sounder click. This is visibly apparent from the graphs: compare the slope of 11-I. and 11-II. with 10-II.; 6-I. and 6-II. with 5-II.; 2-I. and 2-II. with 3-IV. Apparently a large amount of irregularity in the stimuli-series is inconsequential, provided the series is based on a distinct regularity. It will be interesting to find out if this principle can be confirmed and extended in regard to rhythmic series in which each group is marked by an impression whose period from group to group is regular, while the periods of the other impressions are irregularly varied.

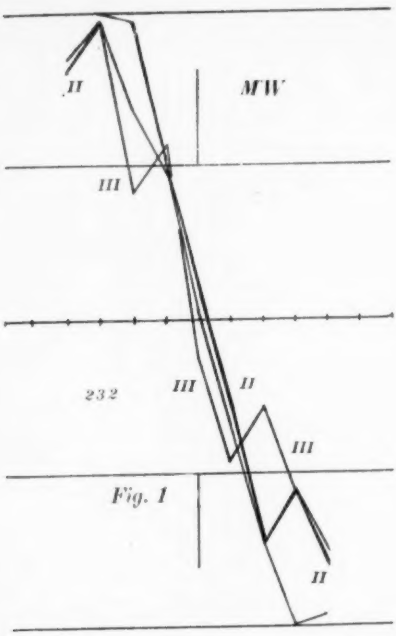


Fig. 1

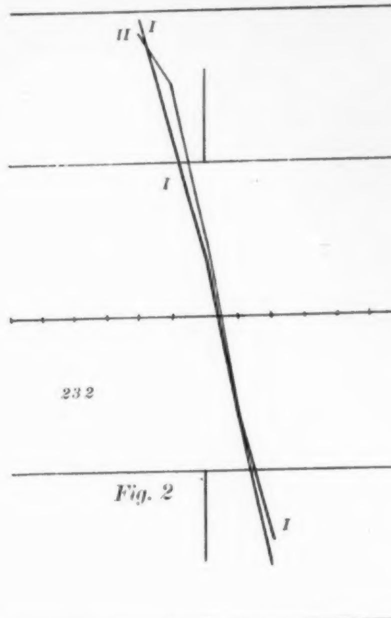


Fig. 2

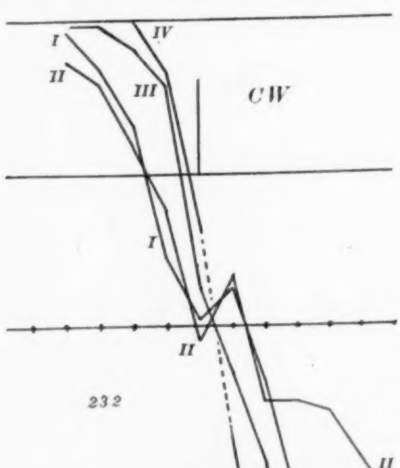


Fig. 3

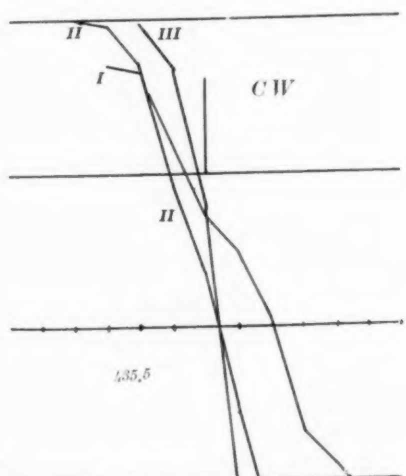


Fig. 4

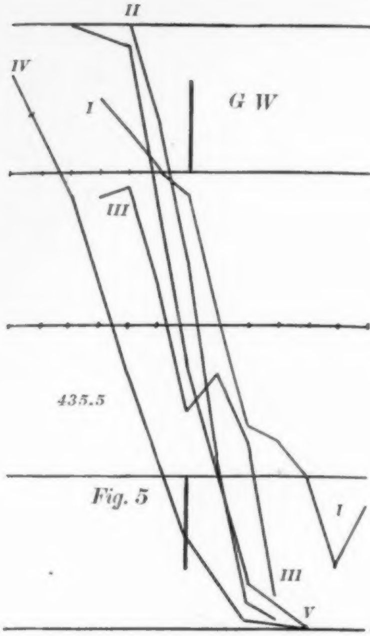
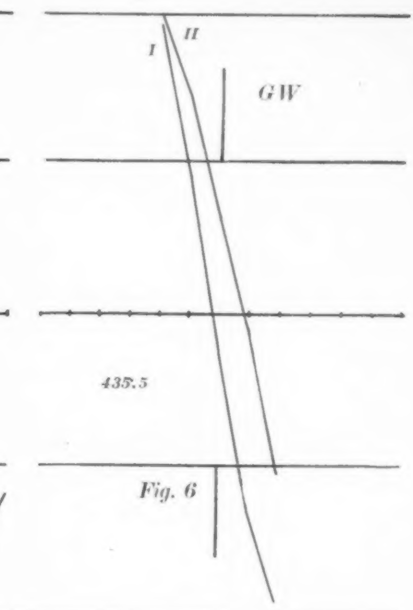


Fig. 5



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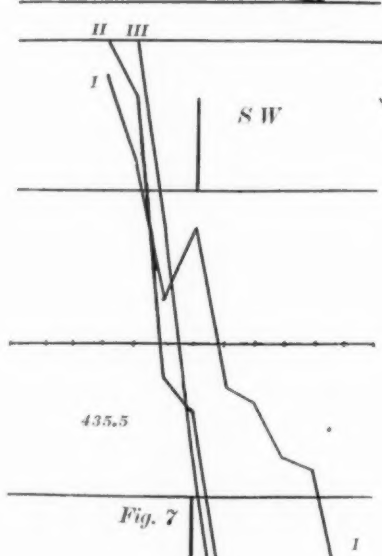

Fig. 7

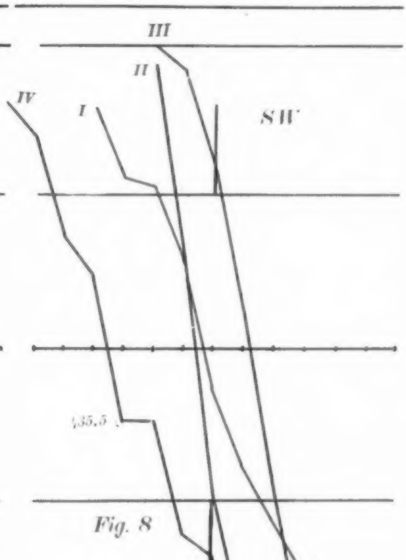

Fig. 8

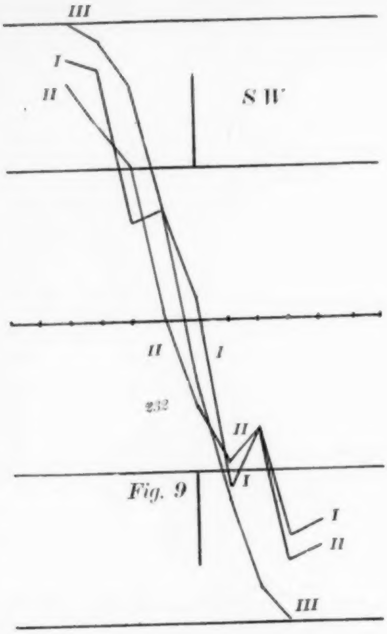

Fig. 9

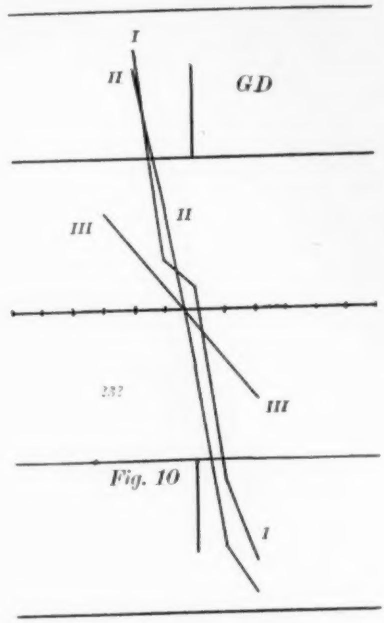

Fig. 10

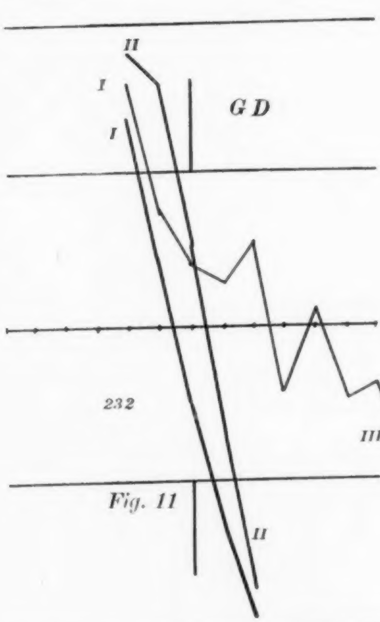

Fig. 11

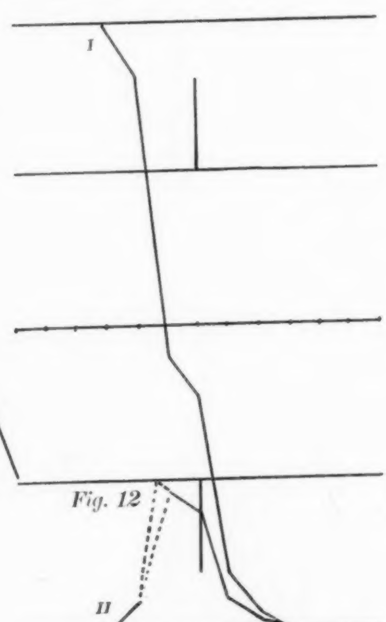

Fig. 12

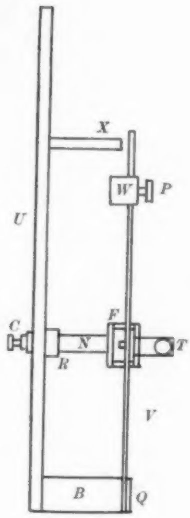

Fig. 13

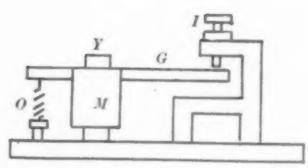

Fig. 15

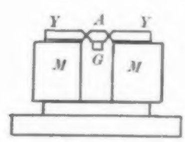

Fig. 16

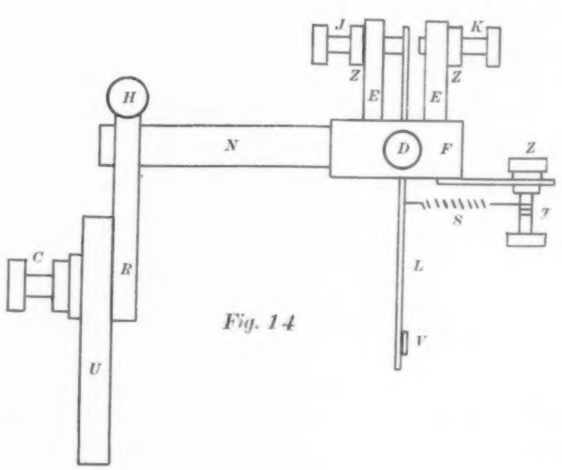

Fig. 14

SOME NOVEL EXPERIENCES[1]

BY H. A. CARR

1. Positive After-Images of Motion

The following curious phenomenon was experienced by Professor Watson, while aiding the writer in a dark room experiment in this laboratory during the summer of 1906. After serving as a subject in a test involving considerable eye fatigue, Professor Watson was engaged in carefully and steadily observing one of the writer's eyes throughout several periods of five to six minutes duration each. The room was pitch dark with the exception that the observed eye was illumined by a miniature electric flashlight. The light was of weak intensity, but all of its rays were converged upon the eye.

After one of these observations, the flashlight was turned off for a period of rest. Shortly afterwards there developed in the darkness an extremely vivid and realistic positive after-image of the eye—the dark iris and pupil, the white sclerotic, and the surrounding lids—all appearing in a faint halo of white light, the positive after-image of the illumination. All of the minor details of coloring and marking came out distinctly. The image was hardly ghostlike in appearance for it appeared too substantial in character; rather it looked alive, and it so dominated consciousness that it could not be destroyed by eye closure, eye movement, nor by diversion of the attention. So uncanny was its life-like reality that the lights were finally turned on in the room in order to escape its persistent presence. The phenomenon had persisted from two to three minutes. Just before the lights were turned on, an added tinge of reality was produced by the occurrence of a wink of the reflex type. Evidently this wink was a positive after-image of the involuntary blinkings occurring during the prolonged experiment. It was decided to repeat the phe-

[1] From the Psychological Laboratory of the University of Chicago.

nomenon at other times and note more carefully the conditioning circumstances.

A similar after-image of the eye was obtained in three tests and five cases of winking were noted. Three of these cases occurred during the duration of one image. Moreover, in one test the image of the eye was observed to rotate several times. The amount of rotation was small but distinctly noticeable. These movements were exact replicas of the small reflex rotations occurring during the observation.

It was found necessary to induce a general fatigue of the observer's eyes before the experiment was successful. A more or less definite period of exposure to the stimulation seemed to be necessary in order to obtain the best results. This period was three to four minutes in length. The after-image did not develop until two or three minutes after the cessation of the stimulation. The image generally existed for a period of five to six minutes. Consequently the after-image of motion might occur eight to ten minutes after the original perception of the movement. No negative after-image of the eye was observed either before or after the positive phenomenon. The positive image fluctuated slightly in intensity. These after-images of motion occurred while the eyes were either open or closed. They were not synchronous with the involuntary blinkings nor with the inhibited tendencies to wink on the part of the experiencing subject, at least so far as he was cognizant of these tendencies. Apparently their occurrence was as given and independent of the subject as any objective phenomenon could be.

Professor Watson has had considerable practice in the observation of after-images and is, apparently, more than ordinarily sensitive to the phenomenon. The writer repeated the experiment but was unable to obtain even a positive image of the eye under these conditions of stimulation.

The novel feature in this phenomenon is the presence of motion in the after-image—the blinkings and rotations on the part of the phantom eye. Positive after-images of motion are common and well-known experiences, but our phenomenon presents a new aspect.

A positive after-image of a moving object successfully fixated during its movement gives the sense of motion. This movement of the image is generally supposed to be due to the momentary persistence of the pursuit movement of the eyeball. The after image of motion also occurs when the eye is stationary during the stimulation. This result is generally explained as due to the fading of the positive after-image streak which does not disappear simultaneously throughout its length. A third case is obtained by fixating a light which by a rapid rotation induces a continuous band of light in which is perceived the motion of the more intense portion. The after-image is a plain band which rotates like a wheel. The band does not present any intense part corresponding to the light which moves in reference to the remaining portion as in the original experience. The circular band is relatively homogeneous and rotates as a whole like a wheel without any of its parts moving in reference to each other. The explanation of this phenomenon is difficult.

Our phenomenon differs from those mentioned inasmuch as it presents a movement within the image itself—a positional change of its parts in reference to each other. Rivalry seems to be the best explanation. In the winking the images of the lid and cornea rhythmically supplant each other. The rotation involves not only the struggle of adjacent contents for dominance but rhythmical changes of size, form, and brightness in certain parts. It is rather surprising that these changes should occur so harmoniously several times in succession as to induce such clear-cut definite effects. It is probable that not all of the changes which one can analytically detect in a rotating eye actually occurred in the after-image; it is more probable that only a few striking sensory changes were present and that the rest was a matter of suggestion.

2. An Illusion of Double Awakening

The following peculiar experience has been reported by a friend of my family. The experience consists of three successive stages. The first stage is a dream in which occurs the usual illusion of being awake. In the second stage the

subject regards the first stage as a dream, but still is under illusion that she is awake at the time. Inasmuch as the transition between the two stages is continuous, although abrupt, the subject is under the impression that she was awakened at this transition. As a matter of fact the second stage subsequently proves to be a dream. The third stage proved to be the normal awakened state in which the subject is aware of the two previous stages and her attitudes toward them. We have, then, two dream stages succeeded by the usual awakened consciousness, and both of the transition points are characterized by the sense of awakening, and consequently the subject experiences the phenomenon of two successive awakenings.

This phenomenon was first reported to the writer while the subject was a member of one of my classes in psychology. The subject was requested to note all the details of any subsequent repetitions of this experience. After an interval of two years it was reported that in the meantime the phenomenon had occurred a number of times in her dreams. The phenomenon is not connected with any special kind of dream. In fact, the actual content of the dreams varied. Owing to the frequency and novelty of the experience and my request for a detailed description, the subject feels sure of the main features of the phenomenon as described. Two additional facts were reported: (1) The sense of being awake during the first stage was not overtly and explicitly present to consciousness. The reality of the experiences was accepted in a tacit, matter of fact way. The awakened attitude in the second stage was, however, explicitly and overtly present, and it was accompanied by a high degree of certainty and assurance. (2) The transition from the first to the second stage was invariably accompanied by a noticeable increase in the apparent illumination of the visual world. Objects stood out with great distinctness, and visual space was more visible and transparent. The difference was similar to that of a room at dusk and under a medium degree of artificial illumination. The luminosity of the second stage was, so far as the subject could recall, always of an artificial character.

Dreams are characterized by one of three attitudes. (1) The subject is often genuinely aware that the dream is a dream. This dream attitude is overtly present to consciousness but with varying degrees of certainty and assurance. (2) The subject may experience the illusory sense of being awake, and this attitude with varying degrees of certainty is explicitly present. (3) The tacit and implicit acceptance of the reality of dream experiences is probably the normal and most frequent attitude. This awakened attitude, however, is not present in an overt and explicit form. While we do attribute the awakened attitude to dreams of this type, yet this attitude probably is read back into the dream from considerations derived from subsequent normal experiences. The attitude may be said to be present during the dream only in a tacit and implicit manner.

The phenomenon which we have described possesses but one novel feature, viz., the illusion of awakening, or the change of attitude at the first transition point. The case must be distinguished from a theoretically possible one in which there is a change from a dream to an awakened attitude, or vice versa, but in which the new attitude refers to the entire dream both preceding and subsequent to the transition point. In the case described the new dream attitude applies only to the first stage preceding the transition. The explanation of the phenomenon probably concerns the apparent increase of the luminosity of visual space. The contrast due to this abrupt change overtly arouses the awakened attitude with its high degree of assurance and as a consequence there is induced the retrospective change of belief as to the character of the preceding experiences. The phenomenon is exactly similar to normal awakening.

It may be suggested that possibly the two transitions represent two real stages in the awakening process. In this sense it is hardly proper to term the phenomenon an 'illusion' of double awakening. Awakening may occur suddenly and abruptly, or it may occur so gradually that the person is unable to designate even within wide limits the point where the dream merged into the awakened state. If the awakening

may be gradual or abrupt, there is no *a priori* reason why it may not occur with two abrupt transitions.

3. Recall through Similarity

A young lady of my acquaintance suffers many frequent memory lapses for immediately preceding experiences. For example during a public musical performance, she may 'come to' with a start at the finish with a keen consciousness that she can not remember anything that has occurred in the meantime. The lapse however does not interfere with her playing. These lapses generally occur during fits of mental absorption to which she is addicted. My interest in the phenomenon was directed toward the question whether these experiences were ever subsequently reinstated and to the conditions and mechanism of their recall. This account refers to one such case of reinstatement by similarity or partial identity. She was walking home one afternoon accompanied by a man who was carrying a package. Upon entering the house, her mother inquired the name of her companion and was told that she had walked home alone. Since both were familiar with these memory lapses, the incident was an occasion for much merriment in the family, and the subject attempted to recall the circumstances without success. On the following day a delivered package attracted her attention, striking her with an unwonted sense of familiarity. While observing the package, the forgotten experiences were fully reinstated, and she was aware in an anticipatory manner that the package was the bond of connection, inasmuch as her companion of the day before had carried a package whose size, shape and general appearance were strikingly similar to that before her.

THE INFLUENCE OF CAFFEIN ON THE SPEED AND QUALITY OF PERFORMANCE IN TYPEWRITING

BY H. L. HOLLINGWORTH

Columbia University

The greater part of the previous work on the influence of drugs has been directed toward the study of relatively simple mental and motor processes, such as reaction times, free and controlled associations, reading, adding, hitting at dots, and especially the production of ergograms. In the present experiment, in addition to the investigation of a series of similarly simple processes to be reported elsewhere, an attempt was made to measure the influence of caffein alkaloid on a more complicated process,—that of performance in typewriting.

Subject No. 2, a woman of 38 years, already fairly proficient in typewriting by the touch method, did not take part in the tests through which the various squads of the larger experiment were put. Instead she made systematic records of her skill in typewriting throughout the four weeks of the experiment. Ruskin's 'Sesame and Lilies' was chosen as the material to be copied, since it is fairly uniform in character and interest throughout and was unfamiliar to the subject. The pages of the edition used contained 27 lines, the lines containing on the average 35 characters (letters and punctuation marks). The pages were placed in a random order on an improvised holder, directly over the machine and on a level with the writer's eyes. Care was taken to keep the lighting conditions as constant as possible and the amount of disturbance through the day at a minimum. The subject corrected all mistakes noticed at the time they were made, and record was made of (1) the time taken to write the standard amount, (2) the number of corrected errors, and (3) the number of errors passing undetected. The time record was

kept by the subject herself, by means of a stop-watch. The errors were counted, after the close of the experiment, by a second person[1] and checked up by a third.

During the first 27 days of the experiment the standard amount was 3 pages. This amount was written 7 times daily, the hours being at 8:00, 9:00, 10:00, 11:00, 2:00, 3:10 and 5:30, in order to distribute the trials as much as possible over the entire day. During the first week only sugar doses were taken, the object being to reach a practice level and to secure perfect adaptation to the conditions of the experiment before the caffein was administered. After the first week caffein alkaloid doses were given, in capsule form, on alternate days, the subject being in no case able to distinguish between the caffein days and the control days. This arrangement gave two days for each of the 1, 2, 3, 4 and 6 grain doses employed. The doses were given in increasing amounts, and in all cases just after the first trial for the day had been made, this time being about 8:30 A.M. When caffein is taken in capsule form its effect does not begin until about one hour after taking. Consequently, besides comparing the absolute amount of work done on caffein days with the amount done on control days, the first two trials of each day may be used as a normal performance for that day and the ratio of the five later trials to this normal computed for both kinds of days.

On the remaining 3 days (the intensive experiment) the subject came to the laboratory daily at 10:00 A.M. and wrote 2 pages each half hour (excepting short intermissions for lunch and dinner) until 9:15 P.M., thus making 19 trials each day. On the first of these three days 3 grains of caffein were taken at 3:15 P.M., just before beginning the 10th trial. On the second day a control capsule was taken at the same hour and on the third day a 6-grain dose of caffein. During these days there was absolutely no evidence of practice effect, the subject having reached her level some time before the intensive experiment began. It should be stated that when the book had been copied through once its pages were shuffled again and rewritten in random order.

[1] For assistance in this laborious part of the study the writer is greatly indebted to Miss Agnes M. Denike, A.B., Barnard, '11.

Rivers has made some use of the typewriting test in his work on the effects of caffein and alcohol by inserting periods of writing between the successive performances on the ergograph. In the case of alcohol neither the speed nor the accuracy of the writing seemed to be affected. "There is certainly no indication of any favorable action of the alcohol" (p. 96). "The errors in typewriting fall into two classes—those which escape notice and those which are noticed and corrected. . . . It will be seen that the latter are not very numerous, and so constant in number that they give not the slightest indication of an alcohol-effect. The uncorrected errors occur more frequently, and show an unmistakable tendency to increase with the rapidity of the work, being most numerous in the second interval of the fifth day, when the amount of work reached its maximum. When this increase with rapidity of work is taken into account, there is no definite indication of any alcohol-effect" (pp. 97–8).

There is, however, a striking discrepancy between these statements of Rivers and the table (p. 96) on which he bases them. The table referred to is given complete below and the discrepancy pointed out because of its bearing on certain results of the present experiment.

(Table III)

Rivers, The Influence of Alcohol and Other Drugs on Fatigue, p. 96

	May 17, No Dose	May 19, Control	May 21, 40 c.c.	May 23, 20 c.c.	May 25, No Dose	May 27, 20 c.c.	May 29, Control	May 31, Control
1st interval:								
Quantity of work.	832	824	841	884	883	847	871	902
Corrected errors.	47	56	86	80	89	74	86	94
Uncorrected errors.	26	30	38	26	39	27	21	31
2d interval:								
Quantity of work.	797	842	805	884	956	897	885	904
Corrected errors.	86	71	80	92	140	99	107	127
Uncorrected errors.	45	46	31	26	42	36	44	19

Contrary to the statements quoted in the preceding paragraph, the *corrected* errors are without exception much more numerous than the *uncorrected*. This, it will later be seen, was also the case in the present experiment. The absolute

numerical proportion between the two types of errors is of course immaterial and even their relative numbers would depend chiefly on the attitude of the subject toward the question of corrections.

In Rivers' experiments with caffein .3 gram of caffein citrate, equivalent in strength to about 2.5–3 grains of the alkaloid, was taken morning and evening for six days, and on mornings only for another 6 days, adequate control doses being employed (gentian and citric acid). The dose was taken 10 minutes before the work began. With respect to speed, this experiment showed "the distinct superiority of the caffein days" (p. 45). The number of mistakes was also determined and "here it came out quite definitely that the drug was without influence."

Of the three most available methods of presenting the results of the present experiment only two show clear results. One might on the one hand map out the efficiency curve for the various days, thus indicating, on each day, the course of the performance before and after taking the dose. But diurnal variations arising from other causes obscure the relatively slight influence of the drug from this point of view. A more satisfactory way is to compare the total amount of work done on the caffein days, after the dose has been taken with the similar records afforded by the control days, thus indicating the general capacity for work rather than the diurnal course of efficiency. Or instead of the total amount of work done we may use to advantage the ratio of this amount to the normal work of the respective days, the normal consisting of the work done before the dose was taken.

From the point of view of speed of performance both of these latter methods show clearly that doses of 1–3 grains of caffein alkaloid are stimulating in their effect while larger doses (4–6 grains) produce retardation. Plate I. records the total time taken for the 6 trials after the capsule was taken, for each of the 19 days of the first series of tests, beginning with the last day before the caffein doses commenced. The broken line follows the records for the control days and the solid line that for the caffein days, the time being recorded in minutes.

The 1 and 2 gr. doses show indication of decided stimulation, but at the 3 gr. dose the curves cross, the larger doses of caffein yielding longer times than those of the control days. Presented in this manner, however, the stimulation is somewhat obscured by the practice effect shown by the curves as a whole.

In order to eliminate this factor of practice to a greater

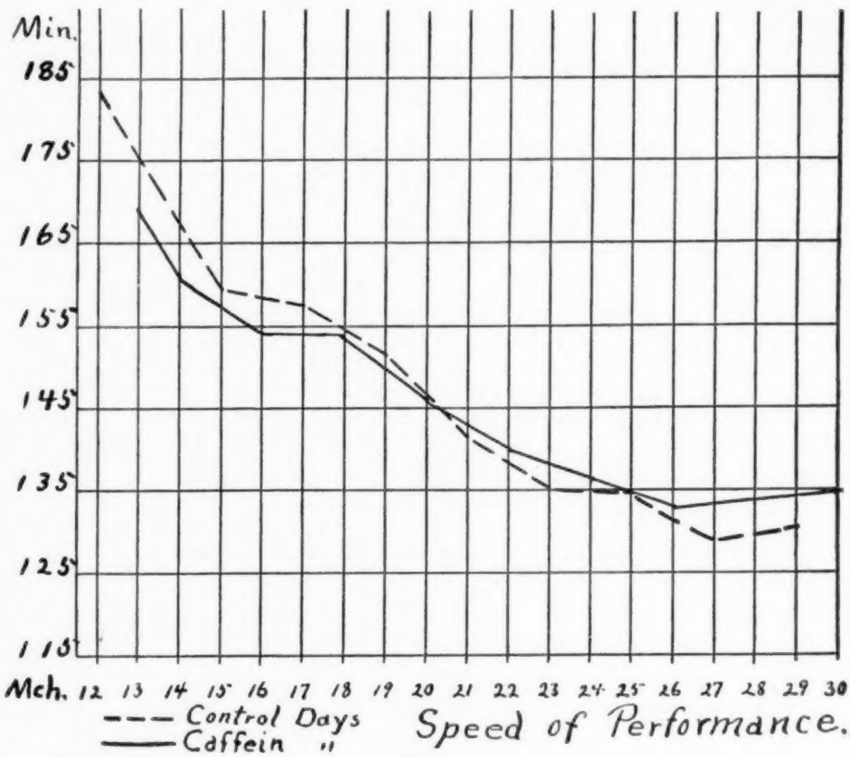

Fig. 1.

degree and to allow for daily variations of an irrelevant sort, I have computed the ratio of the average performance after the dose to the normal performance of each day, this normal being secured by averaging the first two morning trials. These ratios give the curves of Plate II., in which again the broken line represents the ratios for the control days and the solid line those for the caffein days. The effect suggested by

the curves of Plate I. is here very clearly repeated, except that the retardation does not appear until the 4-grain dose is reached. The curve for the control days is practically a horizontal line, showing uniform maintenance of the normal throughout the control days. But the solid line shows improvement over the daily normal after doses of 1–3 grains and retardation below the daily normal after larger doses.

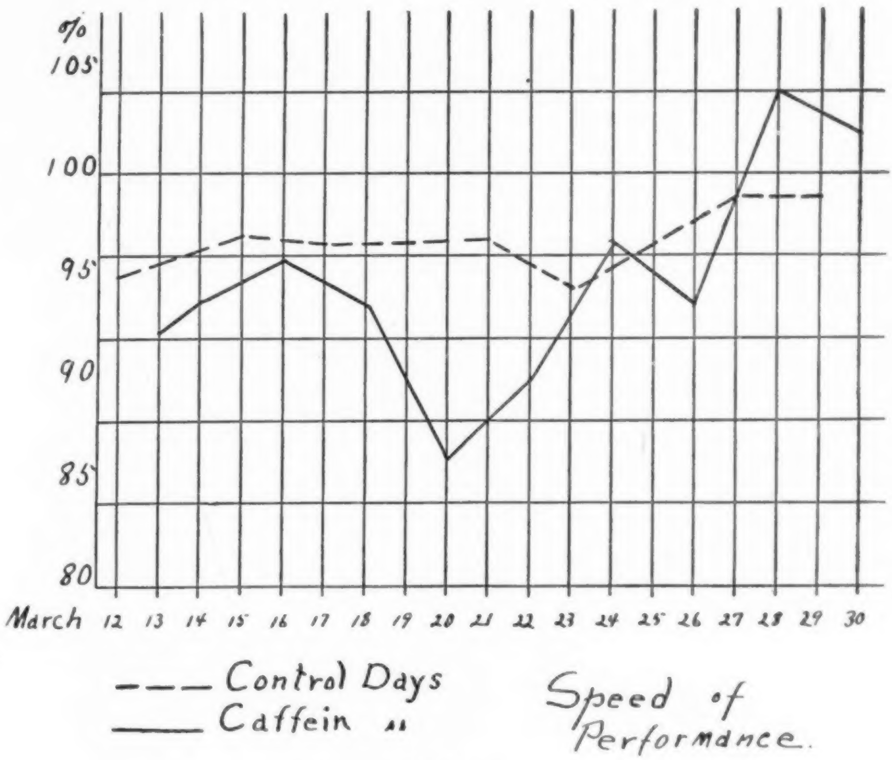

FIG. 2.

Table I. shows the final averages of the daily totals for the last five trials of all the days. The control days and all the caffein days, regardless of the size of the dose, are averaged, and the time, the number of corrected errors, the number of uncorrected errors and the total errors recorded in separate columns.

TABLE I

Averages for	Time	Errors Corrected	M.V.	Errors Uncorrected	M.V.	Total Errors
Control days...	146.7	208	7	73	14	281
Caffein days ...	145.7	201	11	66	13	267

The average times balance, on account of the compensating effects of the small and large doses. The averages for both kinds of errors are smaller on caffein days than on control days, but the mean variations are fairly large and the difference is quite within the range of the probable error. Nevertheless the fact that it is a geniune difference is apparently borne out by the results of the intensive experiments which follow. But the difference is so small that curves corresponding to those for the times fail to show anything clearly.

Table II. gives the results of the three-day intensive experiment, in which 19 trials were made daily, the dose being taken at the time of the 10th or median trial. The table gives the totals for the 9 trials before the dose, comparing these with the totals for the 9 trials following it.

TABLE II

INTENSIVE EXPERIMENT

		First Nine Trials	Last Nine Trials	Difference	Per Cent. Loss or Gain
Time.	Control,	128.6	132.1	+ 3.5	+.027
	3 grains,	130.1	129.5	− .6	−.005
	6 grains,	131.5	131.3	− .2	−.002
Corrected errors.	Control,	189	176	− 13	−.068
	3 grains,	216	156	− 60	−.277
	6 grains,	273	170	−103	−.377
Uncorrected errors.	Control,	35	49	+ 14	+.400
	3 grains,	42	35	− 7	−.167
	6 grains,	59	34	− 25	−.423
Total errors.	Control,	224	225	+ 1	+.005
	3 grains,	258	191	− 67	−.259
	6 grains,	332	204	−128	−.385

These figures confirm the previously drawn conclusions. With respect to speed of performance the slight fatigue present on control days gives place to very slight stimula-

tion on caffein days. The actual difference in time is, however, so slight as to be, in this case, scarcely worth mentioning. And this is what we should expect when the 3- and 6-grain doses are taken. But the difference in the number of errors of both kinds is very great. On control days the corrected errors are slightly less after the dose than before it (– 6.8 per cent.). But after the 3-grain dose they decrease much more decidedly (– 27.7) and after the 6 grains still more so (– 37.7 per cent.). The uncorrected errors are greater for the last 9 trials on control days, clearly less after 3 grains of caffein (– 16.7 per cent.) and strikingly less after 6 grains (– 42.3 per cent.). Compared with the first 9 trials the total errors for the last 9 trials are greater for the control day (less for the 3-grain dose, and still less for the maximum dose of caffein). Contrasted with Rivers' result for alcohol, the time and the errors grow less, simultaneously, and the superiority of the work, from the point of errors, which did not seeem to be present in Rivers' tests of caffein, is clearly shown. But this superiority is seen only when the general capacity for work, over a considerable period of time, is examined. When the results are platted so as to show the course of the performance throughout the day, the curves are obscure.

Summary

The speed of performance in typewriting is quickened by small doses of caffein alkaloid (1–3 grains) and retarded by larger doses (4–6 grains). The quality of the performance, as measured by the number of errors, both corrected and uncorrected, is superior, for the whole range of caffein doses (1–6 grains), to the quality yielded by the control days. Both types of errors seem to be influenced to about the same degree. The increase in speed is not gained at the expense of additional errors, but increased speed and decreased numbers of errors are simultaneously present.

A NEW MEMORY APPARATUS

BY F. KUHLMANN

Faribault, Minn.

The great variety of memory investigations that has of recent years occupied the attention of psychologists has resulted also in a number of different kinds of memory apparatus. A few of these have but a limited use because of the special purpose for which they were designed. Some others have been constructed with the aim of meeting some one or two particular difficulties, and do not fulfill requirements in other directions. The apparatus that I shall describe is for the investigation of visual memory. It has some new features, but the chief aim has been to combine as many good points in one piece as was possible, and to produce an apparatus that would enable one to control as many as possible of the factors that enter a memory experiment, and which experience has taught require control. There are three parts to be described. (1) The exposing apparatus. (2) The apparatus for controlling the exposure interval. (3) The apparatus for controlling the retinal image.

The exposure apparatus consists essentially of a rectangular carrier frame running on four wooden rollers between two upright steel rods. This part is shown in Fig. 1, and the other accompanying cuts will help to make the description clear. Two of the rollers are supplied with small coiled springs that keep the tension and friction of the rollers against the uprights constant. The frame carries in its grooves a thin cardboard eight and a half by eighteen inches on which the memory material, if verbal, is typewritten in vertical columns, with a distance of two thirds of an inch between successive terms of a column. This is the distance of the line spacing of most typewriters. The carrier frame is held from dropping by the padded ends of two levers which come together like the two jaws of a pair of pinchers against the sides of a

vertical centerpiece of the frame, as seen in the cut, these levers being pulled together by two coiled springs. A pair of electro-magnets with proper attachments releases the tension of these springs when the circuit for the former is closed, and allows the carrier to drop till the circuit is broken again. The centerpiece of the carrier frame consists of alternating strips of brass and insulating material, a strip of either being two thirds of an inch high, and this is the distance the carrier will drop each time the electro-magnet circuit is closed. Figure 2 shows how this is accomplished. In Fig. 2, *a* represents the two mounted contact discs of the apparatus for controlling the exposure intervals and which is shown in Fig. 3. *b* is the centerpiece of the carrier, made up of the alternating strips of insulating material and brass, the latter being all connected with each other by a strip of metal in the back. *c* is the pair of electro-magnets. 1 and 2 are contact brushes, one set two thirds of an inch above the other, resting against the centerpiece. 3 and 4 are contact points which the teeth of the contact discs engage alternately as the two discs turn together on a common shaft. It will be seen that as the further contact disc closes the circuit at 3, and it being also closed at 1 resting on a brass strip, the carrier will drop until the brush at 1 slides onto the next and insulating strip, when the circuit is broken, allowing the springs to pull the levers together again. The brush at 2 will now be on a brass strip closing the other circuit at this point, and when the nearer disc turns to close this circuit at 4 the operation is repeated, and so on.

This part of the apparatus aims to accomplish the following results. (1) An easy means of making up a large amount of memory material. If the material is verbal, it is seen that it can be prepared as fast as it can be typewritten. (2) To bring each term of a series suddenly into view and out again. (3) To make the exposures noiselessly. Space will not permit discussing the importance of these points. The second and third have been discussed in connection with the description of other memory apparatus, and it will be understood by all students of the subject. The apparatus is at present not

entirely inaudible to the observer seated at a distance of three feet from this part, when he directs his attention to that noise. It becomes entirely inaudible at once when he directs his attention to memorizing the material that the apparatus exposes. I hope in the future to make some alteration that will make it absolutely inaudible for the distance at which the apparatus is used. The principle employed is that of avoiding the use of any two surfaces striking together in the moving parts. The padded ends of the levers holding the carrier frame hardly move visibly, and the padded surfaces do not break contact in this movement with the sides of the vertical centerpiece.

The part for controlling the exposure intervals is shown in Fig. 3. It consists of a pair of discs with contact teeth, and which are mounted on opposite ends of a common shaft. These discs are turned by a ratchet wheel and a pair of electro-magnets with proper attachments. A metronome with electrical contact attachments may be substituted for this controlling apparatus, if the successive exposure intervals are all to be of the same length. But the present controlling apparatus is intended to give the exposures in pairs, with the two exposures of a pair of unequal length. For example, a term of a series is exposed for one second, when it drops out of sight and the apparatus shows a blank on the card for three seconds, then the next term is shown again for a second followed again by a blank for three seconds, and so on. The nature of the exposure intervals given will depend then on four things: (1) The rate at which the electro-magnets drive the discs; (2) the number of teeth in the ratchet wheel; (3) the number of contact teeth in the discs; (4) the relative setting of the discs on the shaft with reference to how closely a contact on one disc is followed by the next contact on the other disc. It will be seen from a little computation that with only a few pairs of contact discs with different number of teeth and two ratchet wheels a large number of different exposure intervals may be obtained even with only one rate of driving of the discs. The present apparatus was supplied with two ratchet wheels with thirty and thirty-two teeth, respectively, and ten pairs of contact discs

with the following numbers of contact teeth: 1, 2, 3, 4, 5, 6, 8, 10, 15, 16. In Fig. 4 all of the apparatus is shown set up together, and a Zimmermann contact clock is used here to make and break the circuit for the magnets that turn the discs. A metronome might replace the Zimmermann clock, but would not be quite as convenient. With the Zimmermann clock a relay is used to guard the former from injury from the heavier current that the rest of the apparatus requires. This relay is shown in front of the contact clock. This part of the apparatus is not noiseless and should be placed in a sound-proof box or set up in an adjacent room.

The object of following the exposure of each term with a blank exposure of perhaps a different duration is to give an exact and independent control of two processes that are always present in memorizing any kind of material. These processes are the perception, pure and simple, of the term, and its immediate re-imaging or recall, before the next term is given, in the case of successive presentation. I have found in different memory studies that every observer always uses a good portion of the total time, a half to two thirds, for this latter process, when all the material is shown simultaneously. When the terms of the material are shown successively the same holds true, so much so, that an observer will often fail to see a term because his attention is engaged in recalling the one that has just preceded. The possible importance of this immediate recalling process may be seen in the fact that the observer naturally uses so much time for it, and in results which show that the time thus spent may be three times as effective for memory as when that same time is used in further perception merely. This relative importance of the perceptive and the immediately recalling processes, further, seems to vary with the type of the individual observer. It thus becomes quite evident that we should have a means of controlling these two processes independently, so that the experimenter may know just what takes place in the observer's mind. The observer may be instructed as to how to use these two intervals, the exposure of the term and the blank exposure, in order to attain this end.

The apparatus for controlling the retinal image is shown in Fig. 4 on the right. It consists essentially of a large camera with a dark chamber back of the ground glass on which the observer sees the image of whatever the exposing apparatus shows. This dark chamber can be lengthened or shortened independently of any change in the distance between the lens and ground glass. It is supplied with a hood through which the observer looks, not visible in the figure, so that no light strikes his eyes except what comes from the ground glass, thus isolating the observer from all distracting visual stimuli. This arrangement, then, gives a means of varying the size of the image on the retina, and the distance for which the eyes have to be accommodated, independently. The intensity of the light is adjusted with the stop with which the lens is supplied. This part of the apparatus is of course not required if it is not desired to control these factors in the manner described. The parts shown in Figs. 1 and 3 were built by C. H. Stoelting and Co., of Chicago.

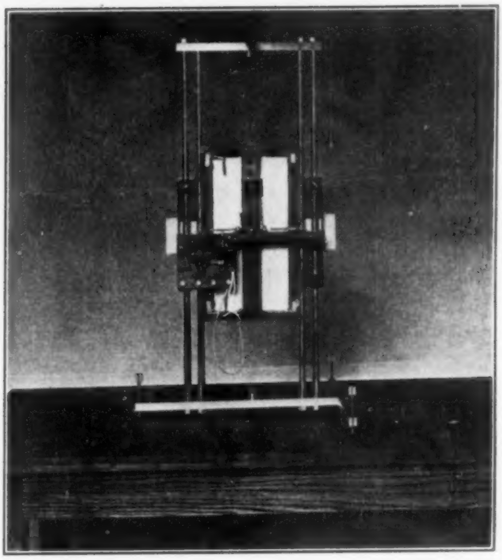

FIG. 1.

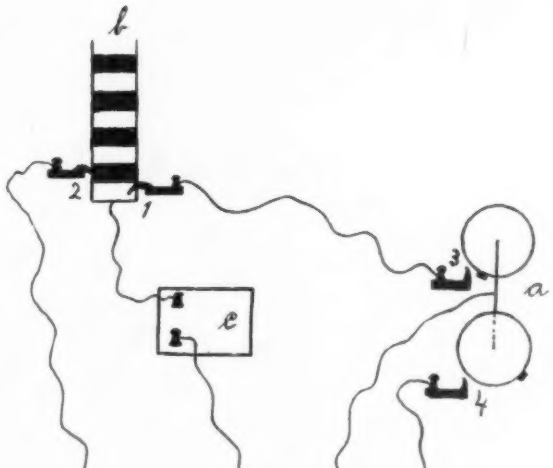

FIG. 2.

PLATE I.

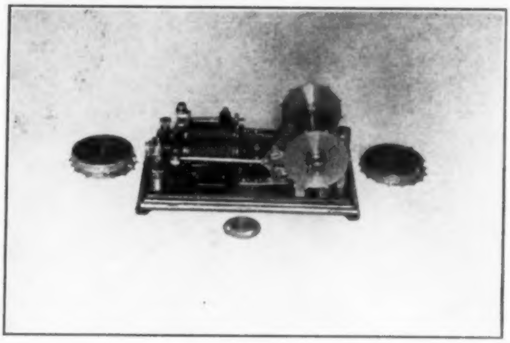

Fig. 3.

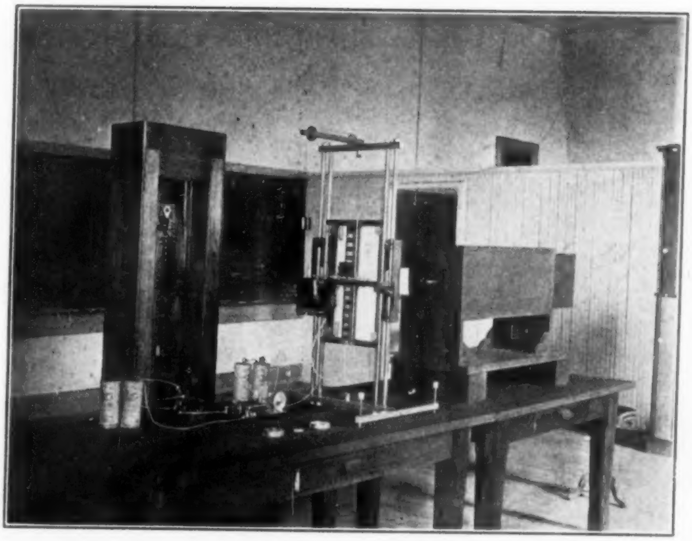

Fig. 4.

PLATE II.

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